N67-25481

N67-25452

FINAL REPORT

for

A STUDY OF THE EFFECT OF SPACE RADIATION ON SILICON INTEGRATED MICROCIRCUITS

VOLUME I

(29 June, 1965 to 31 August, 1966)

Contract No. NAS5-9630

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SUMMARY

Ten silicon integrated-microcircuit types representing four of the more recent developments - digital micropower circuits, digital dielectrically isolated circuits, digital MOS circuits, and amplifier circuits - were exposed to electron radiation until failure. Electrons with energies of 3 Mev were used for all device exposures except the MOS digital circuitry, which was exposed to 1.5 Mev electrons. The fluence at which first failures occurred varied from $<5 \times 10^{11}$ e/cm^2 to 6×10^{13} e/cm^2 for the amplifiers, 8×10^{14} e/cm^2 to 1.45×10^{15} e/cm^2 for the micropower circuits, $<1.2 \times 10^{11}$ e/cm^2 to $<2.5 \times 10^{12}$ e/cm^2 for the MOS circuits, and 4.15×10^{14} e/cm^2 to 3.94×10^{15} e/cm^2 for the dielectrically isolated circuits. Failure was defined as exceeding the manufacturer's specified parameter limits. Each microcircuit type was represented by four test groups, each containing five circuits. One test group was maintained as a control. The other three were irradiated under different electrical conditions: dynamic, worst-case a-c operation, worst-case static operation, and nonenergized except for periodic pulsed measurements.

The over-all purpose of this program was to determine

(1) Whether or not any class of microcircuits is inherently superior to others in the radiation environments

(2) What, if any, steps the system designer can take to prolong the useful life of the microcircuits in the radiation environment.

(3) What effect the electrical condition of the microcircuits during irradiation has on the radiation-induced degradation.

(4) What component changes are the responsible mechanisms for device parametric changes, and what steps can be taken by the fabricator to improve microcircuit radiation resistance.

The results of the experiment are discussed below.

Effects Versus Microcircuit Class

This study has demonstrated that the predominant mechanism of microcircuit failure is the decrease of transistor gain or changes in gate threshold voltage. The mode of failure for digital circuits is not necessarily an increase in saturation voltage of one or more transistors at the output of the microcircuit. The MOS digital circuits can have failures caused by a decrease in the logical "one" voltage. This decrease appears to occur as a result of increased drain-leakage current. The mode of failure for the amplifiers was attributed to three basic parameter changes: decreased gain, increased input bias current, and increased offset voltage. Any one of the above parameter changes can be the predominant cause of failure, depending upon the specific circuit configuration.

The results of this program indicate that the present MOS digital circuits exceed the circuit specifications at lower radiation exposures than the other three classes studied. The amplifier circuits also appear to have inherent traits resulting from matching and balancing components which will make them less radiation resistant than the better digital circuits, but generally better than the present MOS circuits. Data pertaining to the remaining classes, micropower and dielectrically isolated circuits, were not sufficient to generally rate the radiation resistance of the classes except to indicate that they are as resistant or more resistant to radiation than the amplifier circuits. The analysis indicates that the construction of the transistor and the tolerance of the microcircuit design to transistor gain or gate threshold degradation or small changes in leakage current are of great significance to the radiation response of the microcircuit.

Extrinsic Design Considerations

In the majority of cases, a reduction in permissible fan-out will increase the longevity of the digital microcircuits in a steady-state radiation environment. However, for MOS digital circuitry this is not necessarily the case. A decrease in the logical "one" output level can result in failure before that attributed to a "zero" level increase. The decrease in the "one" level appears to be a direct result of drain leakage and is not necessarily affected to any great extent by the magnitude of the load.

Also for the digital MOS circuitry, the input threshold voltages increase substantially as the output low-level voltages increase. Hence some degree of compensation is possible, but provision must be made at the subsystem interfaces to accept the changed logic levels. This step may require a reduction in noise margin and involve environmental and design tradeoffs.

Several design considerations can be incorporated in amplifier circuitry to help reduce the effects of radiation

(1) Choose a feedback network that has sufficiently low resistance to swamp the expected increase in leakage current.

(2) Use balanced low-input resistances to ground to reduce leakage-current effects.

(3) Since the input offset voltage is also likely to increase, a-c coupling should be employed for cascaded amplifier stages.

Effects of Electrical Condition

In some of the circuit types, no statistically significant differences were observed among the irradiated test groups. The differences were masked somewhat by the high variability resulting from small sample size. The differences which were noted, however, appeared to depend on the sensitivity of the circuit and the type of damage causing the failures. That is, the circuits that appeared to be failing from surface damage showed less degradation for the unbiased units than for the biased units. However, the circuits that appeared to have some damage due to bulk effects seem to show more degradation for the nonenergized circuits than for the energized circuits. Nelson and Sweet(1), working on this general problem, have developed a model to help explain this effect. It is not apparent, however, that their solution can completely account for the observed changes.

Observing the changes in pulsed measurements during and immediately after exposure indicated no excessive temporary changes.

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(1) Nelson, D. L. and Sweet, R. J., "Mechanisms of Ionization Radiation Surface Effects on Transistors", IEEE Annual Conference on Nuclear and Space Radiation Effects, Palo Alto, California (July 18-22), work performed under contract number NAS8-20-135.

Intrinsic Design Considerations

The point of failure for all categories of circuits has centered around the transistors. Whether it was transistors operating at very low current levels with leakage currents becoming an appreciable part of the current being controlled, or whether failures were due to increased gate threshold voltage or decreased gain resulting from surface or bulk damage, the problem device is the transistor.

The failure of the μA709 was an increase in input offset voltage due possibly to an unbalance of input leakage current through the input transistors. On the other hand, the SE505G and A13251 failed due to a decrease in amplifier or transistor gain. The micropower circuits PL987 and WS113Q failed due to an increase in output transistor saturation voltage and decreased gain. The MOS circuits 7532, 7531, and μM400 generally failed as a result of increased threshold voltage. The dielectrically isolated circuits RD210 and EPIC-DTL experienced failures due to increased output saturation voltage and decreased output transistor gain. These results are not new and were generally expected.

It appears as though a significant improvement could be obtained by the fabricator of minority carrier devices by increasing transitor f_T and widening circuit margins with respect to transistor gain. The majority carrier devices and several of the minority carrier devices apparently degraded due to surface damage. The surface problem is not well understood and needs a great deal of research. Surface problems, however, can be suppressed somewhat by techniques which have been discussed in the open literature and are well known by the manufacturers.

In circuitry which will have transistors operating at low power levels, consideration should be given to the effects of increased leakage currents. Adjusting for increased leakage may require an adjustment of allowed operating margins and/or a redesign to include compensating circuitry.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The increasingly demanding performance and reliability requirements for space-flight systems makes it imperative that designers use the most effective and reliable circuitry available. Component selection for space programs, however, must be made with due regard to the behavior of the components under their intended operating environment. Of particular importance is the radiation environment of space.

The use of silicon integrated microcircuits in electronic design offers many potential advantages. Included among these are small size and low weight, intrinsically high reliability, good performance, and low cost. Under contract with the Goddard Space Flight Center (NAS5-3985) from June, 1964, to September 1965, Battelle studied the effects of electron radiation on several digital microcircuit types representative of the prevalent technology. Since the initiation of that study, developments in the silicon integrated technology have progressed rapidly. Commercial analog microcircuits have demonstrated capabilities to effectively perform many linear system functions. In the digital area, newly developed fabrication techniques have been applied successfully to realize improved performance with respect to power consumption, operating frequency, and electrical isolation.

In order for NASA to accumulate and maintain the required information upon which to base its decisions for microcircuit utilization and/or microcircuit improvement efforts, it is necessary that experimental radiation-effects data be obtained for these current microcircuit developments in both analog and digital areas. As a result, the current program

(NAS5-9630) was initiated with the purpose of classifying four classes of integrated circuits according to their electron-radiation susceptibility.

Three classes of integrated circuits, digital micropower circuits, digital dielectrically isolated circuits, and amplifier circuits, were exposed to 3 Mev electrons. The fourth class, digital MOS circuits, was exposed to 1.5 Mev electrons. There were 20 devices of each of ten circuit types representing eight manufacturers. The specific objectives of this program were to evaluate the performance of the devices as a function of radiation exposure by (1) characterizing the microcircuits with respect to critical parameters that determine their performance in systems applications and that can be readily correlated with fundamental device parameters, (2) irradiating the devices in an electron environment with appropriate measurements being made during the radiation exposure, (3) repeating the initial characterization measurements, and (4) analyzing the data obtained in an appropriate manner.

TECHNICAL DISCUSSION

General

The over-all program plan illustrated in Figure 1 was followed in evaluating the microcircuits. Of primary importance in the evaluation of these devices in the radiation environment is the initial and final electrical characterization. The nature and the extent of this characterization is discussed in detail in the section entitled "Characterization".

Since it is of interest to determine both the mode of interaction between the incident radiation and the microcircuits and the duration and degree of permanency of any deleterious effects that occur, it was

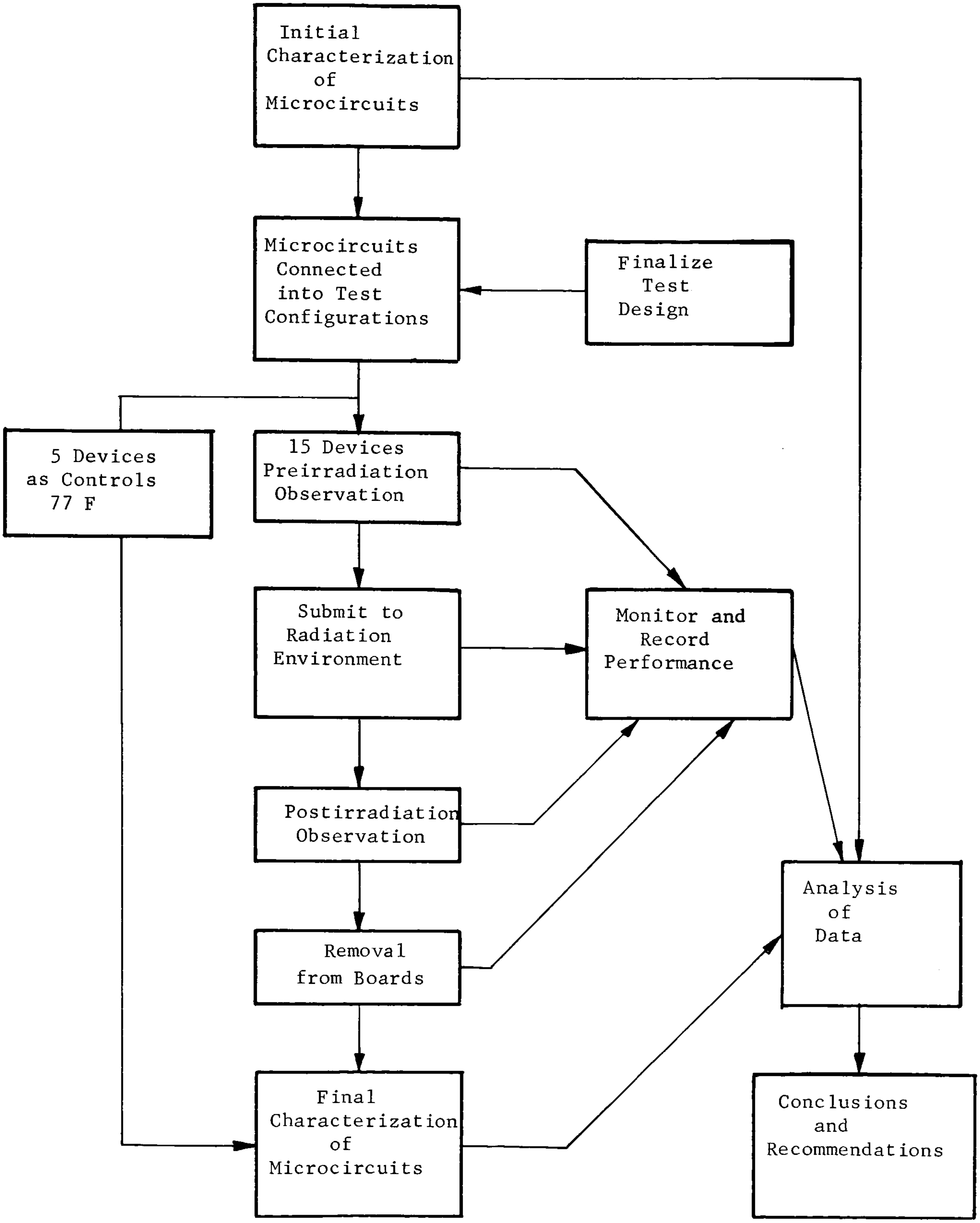

FIGURE 1. OVER-ALL PROGRAM PLAN

desirable to monitor the electrical characteristics of the microcircuits while under, and immediately after, radiation exposure. The inability to manipulate the microcircuits during the relatively short irradiation period made it necessary to limit the measurements to a few selected parameters that would be most indicative of the electrical conditions of the microcircuits. To accomplish this objective, the 20 devices of each type were grouped in the following manner: 5 devices were held as control samples (not irradiated), 5 devices were irradiated but not operated (except periodically, when a short 8 μ second bias pulse was applied in order to take a measurement), and 10 devices were irradiated in an operating condition (such as a part of a counter or oscillator, or in an amplifier chain). The electrical characteristics which were monitored during irradiation were the output levels and frequency of oscillation or counts. A detailed discussion of the monitoring during irradiation is presented in the section entitled, "Monitoring and Test Configurations During Irradiation". Postirradiation observation of the operating devices was continued until the parameter drift was no longer pronounced. The operating devices were then disconnected and the unbiased samples connected to the statically operated device-monitoring equipment. This postirradiation observation of the unbiased circuits operating in the static configuration was continued until the parameter drift was no longer pronounced or for about 15 minutes. All devices then underwent a postcharacterization similar to the initial one.

As shown in Figure 1, the results of the characterization measurements and the test-configuration observations were analyzed in order to reach conclusions regarding the relative performance under radiation of the several classes of microcircuits considered. The final products of these last steps appear in the sections entitled "Analysis of Data" and "Conclusions and Recommendations".

Selection of Microcircuits

The microcircuits to be evaluated in this program (shown in Table 1) were linear amplifiers and advanced digital types. Of interest in the latter types are digital functions distinguished by their methods of construction (dielectric isolation or use of MOS active elements) or by their power consumption. The selection of these classes of devices for this program was based on the individual merits of each class and NASA's needs.

Amplifier Circuits

The amplifier microcircuit classification was selected because it was felt to be an area which would be readily used once a variety of devices were commercially available. It was also felt that this class might be sensitive to space radiation because of the design criticality of the amplifier's circuitry. It might be expected that changes in the delicate input balance conditions could disrupt the device operation at relatively low electron fluences causing a system malfunction.

Micropower Circuits

The selection of micropower digital circuitry is a desirable choice from two standpoints. With reduced power requirements one can either increase the number or complexity of the electronic functions

TABLE 1. DEVICES USED IN PROGRAM

Circuit Type	Mfg.	Code No.[a]	Function
	Analog Silicon Integrated Circuits		
μA709	Fairchild	A-7	Op Amplifier
A13251	Amelco	H-1	Op Amplifier
SE505G	Signetics	C-3	Dif Amplifier
	Micropower Digital Integrated Circuits[b]		
PL987	Philco	I-1	T^2L Gate
WS113Q	Westinghouse	J-4	Flip-flop
	MOS Integrated Circuits		
7532	General Instrument	K-1	Gate
7531(MEM529)	General Instrument	K-2	Flip-flop
μ M400	Fairchild	A-8	Transistors[c]
	Digital Dielectrically Isolated Integrated Circuits		
RD 210	Radiation Inc.	G-1	DTL-Gate
EPIC DTL	Motorola	B-3D	DTL-Gate
MC962	Motorola	B-3M	Monolithic DTL-Gate[d]

a - Code number used to identify circuit types in all appendixes of this report

b - Circuits with less than 500 microwatts average power drain per gate elements

c - The package contained 5 MOS transistors. These were externally connected to form a gate. The μM400 is now sold by the number μM-3400.

d - Observed by mistake.

performed on a space mission with the same amount of allowed power, or decrease the payload by decreasing required power storage and collection elements. Either choice results in a more efficient use of the available space-program funds.

MOS Circuits

The selection of MOS active element digital circuitry is a logical extension after choosing micropower devices. MOS devices with their very low current requirements can function, if desired, at very low power levels. With the use of MOS FET's in the digital circuitry the circuitry has much higher noise margin. The exclusive use of MOS FET elements in the digital circuitry eliminates the problem of manufacturing high resistances ($\sim$ 100k) either by thin-film or diffusion techniques, a problem which has hindered the development of diffused micropower circuitry. In MOS digital circuitry, resistances are achieved by biasing an MOS device to an operating point which gives the desired resistance value. Of course, by changing the operating point, the resistance value changes and this value can be adjusted for the optimum circuit operation. Even though the MOS devices appear to have several desirable features for use in space applications, currently available devices have one apparent shortcoming: limited radiation resistance. Extensive programs(2) examining discrete MOS FET's indicate that they

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(2) Wannemaker, Harry E., "Gamma, Electron, and Proton Radiation Exposures of P-channel, Enahncement, Metal Oxide Semiconductor, Field Effect Transistors", Goddard Space Flight Center, Greenbelt, Maryland, X-716-65-351, (August , 1965).
Gordon, Frederick, and Wannamaker, Harry E., "The Effects of Space Radiation on MOSFET Devices and Some Application Implications of Those Effects", Paper presented at IEEE Annual Conference on Nuclear and Space Radiation Effects, Palo Alto, California (July 18-22, 1966).

strongly degraded at a relatively low radiation fluence, $\sim 10^{12}$ e/cm^2. As a result one would also expect the MOS digital circuitry to fail at relatively low electron exposures. Hence these devices if used in a space system may be the point of first failure for the system.

Dielectric Isolation

The dielectric isolation of digital circuitry offers possibly a better and more versatile method for obtaining electrical isolation than the diffused-junction approach in monolithic integrated circuits. Some of the electronic features of dielectric isolation in comparison with diffused-junction isolation are

(1) Approximately 10:1 improvement in element-to-element capacitance enhancing the possibility of higher-speed devices

(2) Capacitance value independent of applied voltage

(3) Approximately 1000:1 improvement in element-to-element leakage current

(4) About 20:1 improvement in element-to-element breakdown voltage

(5) Selective gold-doping is practical for control of minority-carrier lifetime.

The circuit configuration (i.e., RTL, DTL, etc.) was not considered in the decision on the digital-device types since the preceding research program[3] indicated no evidence that any logic configuration was inherently superior to another.

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(3) NASA Contract Number NAS5-3985, "A Study of the Effects of Space Radiation on Silicon Integrated Microcircuits". (June 26, 1964 - September 26, 1966)

The final selection, however, was constrained by the fact that most part types of interest were either not yet commercially available or could be obtained in only limited numbers. As a result of this constraint, the cooperation of the circuit manufacturers was necessary.

Test Groups

As indicated in the introduction 20 devices were obtained for each circuit type studied. After initial characterization, each set of 20 devices was randomly divided into four subsets of five devices each. One subset contained the control units, which were not irradiated. The control samples served as a check on the reproducibility of the measurement conditions and as a reference for any change in the device type.

A second subset was the dynamic test group. The dynamic test group of digital circuits was irradiated either in an oscillator or counter configuration, depending on the device type. The dynamic test group for amplifiers consisted of cascading five amplifiers with closed loop gains of 100 and 100:1 dividers on each amplifier output except on the last amplifier of the chain. A nonsaturating sinusoidal signal was fed into the first device in the series.

A third subset called the static test group was irradiated in a test configuration for the digital circuits that permitted both the "on" and "off" output states to be observed during irradiation. The amplifiers had closed-loop gains of about 100 and four d-c output levels were observed during the exposure.

The fourth subset, the nonenergized test group, was irradiated without bias. However, periodically a pulsed measurement of short duration (~8 μ seconds) was made on the devices. The module numbers included in each grouping are shown at the bottom of each raw data sheet.

Characterization

The characterization serves two purposes:

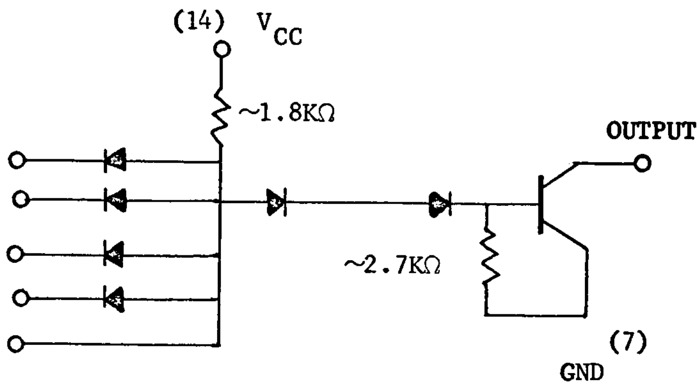
(1) To determine, for design and application use, the pertinent changes in device parameters due to the radiation

(2) To determine the effects of radiation on the individual components by means of terminal measurements.

The plans for the characterization were developed in three parts. The first part consists of a schematic of the circuit (Figure 2), general test conditions, the tests to be performed, and comments of a general nature. The second part consists of a general view of the individual tests, as represented by Figures 3 and 4 for gates, Figures 5 and 6 for flip-flops, and Figures 7 and 8 for amplifiers. The third part consists of the detailed test plans and data. All three parts of the characterization plans are presented in Appendixes I and III, Volume II.

Problems During Characterization

Delivery of parts on schedule was a major problem during the initial characterization period. Parts were arriving up until it was time for the irradiation. In some cases a few of the received parts were very marginal with respect to the specification as decided by Battelle and the manufacturer. The marginal parts were returned in exchange for other parts. It is felt that these problems have arisen from trying to do the work with devices which in some cases were primarily developmental. Another small problem area was the extra care needed in handling of the MOS digital-circuit measurements. Also, some measurement problems occurred with the amplifiers, TEST PLAN for RD210



TEST CONDITIONS

1. Pin 14 - 5.0 Volts
2. Pin 7 - ground
3. Temperature 77 F

TEST PARAMETERS

1. Input Voltage Levels ($V_{min\ one}$ and $V_{max\ zero}$)
2. Input Drive Current
3. Input Leakage Current
4. Output Drive Current Capability
5. Transient Parameters
6. Forward Diode Voltage
7. Resistance
8. Circuit Gain
9. Output Saturation Voltage

FIGURE 2. TYPICAL CIRCUIT SCHEMATIC

CHARACTERIZATION PLAN (GATES)

CIRCUIT TYPE: RD210

BASIC CONDITIONS	NOTES
V_{cc} = 5.0 volts on pin 14 Temperature 77 F Ground pin 7	$V_{min\ one}$ = 4.0 volts $V_{max\ zero}$ = 0.400 volts

		PARAMETER	APP. TEST	CONDITIONS
FUNCTIONALLY STATIC	Input	$V_{min\ one}$		With a fanout of 1 and 8
		$V_{max\ zero}$		With a fanout of 1 and 8
		Drive Current Requirement		Input grounded through milliammeter output pullup resistor = 1.8K ohms.
		Leakage Current		Apply 5.0 volts to pin 1 and ground pin 3 through a μammeter.
	Output	Drive Current Capability		Apply 4 volts to all inputs. A variable resistor from V_{cc} to output is reduced until output volt is 0.400 volts. Record output current at this point.
		Leakage Current		Does not apply
DYNAMIC	Transient	Rise, Fall, Storage, and Delay Times		Output with a pull-up resistor of 1.8K ohms.

FIGURE 3. CHARACTERIZATION PLAN (GATES-SHEET 1)

CIRCUIT TYPE: RD210

	PARAMETER	APP. TEST	CONDITIONS
	Forward Diode Voltage	6	Adjust the current through the input diode to 2.6 ma and record the voltage.
	Resistance	7	The resistance between pins 3 and 14
	Circuit gain	8	Once test 7 is performed the current into the base of the output transistor can be adjusted. With the collector voltage at 0.50V determine circuit gain.
	Output Saturation Voltage	9	Load output to V_{cc} adjust load until there is an output current of 22 ma. Measure V_{SAT}.

ENGINEER R. K. Thatcher DATE 10/28/65

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FIGURE 4. CHARACTERIZATION PLAN (GATES-SHEET 2)

CHARACTERIZATION PLAN (FLIP-FLOPS)

CIRCUIT TYPE WS113

BASIC CONDITIONS	NOTES
Temperature 77 F V_{cc} = 3.0 volts on Pin 6 Ground on Pin 1 Pin 5 open	STANDARD CLOCK PULSE: WIDTH, 1μsec ; REP. RATE, 500 KC ; AMPLITUDE, 2.5 volts $V_{max\ zero}$ = 0.5 volt $V_{min\ one}$ = 2.5 volt

		PARAMETER	APP TEST	CONDITIONS
FUNCTIONALLY STATIC	INPUT	DIRECT SET-RESET INPUT THRESHOLD	1	Increase the direct set and reset voltage levels until output changes from high to low state.
		DIRECT SET-RESET INPUT DRIVING CURRENT	2	Read current when direct set and reset voltage levels are 2.5 volts.
		DIRECT SET-RESET INPUT LEAKAGE CURRENT		Not Performed
		CLOCKED SET-RESET INPUT THRESHOLD	3	Apply standard clock pulse -- Increase clocked set and reset input voltage levels until output changes state. No load.
		CLOCKED SET-RESET INPUT DRIVING CURRENT	4	Read current when clocked set and reset voltage levels are 2.5 volts.
		CLOCKED SET-RESET INPUT LEAKAGE CURRENT	4	Read current when clocked set and reset voltage levels are 0.5 volts.
		MINIMUM PULSE WIDTH AND HEIGHT (CLOCK PULSE)	5	Start with standard clock pulse -- vary width and height independently. With the device connected as a counter locate minimum pulse width and height required for proper operation.

FIGURE 5. CHARACTERIZATION PLAN (FLIP-FLOPS-SHEET 1)

CIRCUIT TYPE WS113

		PARAMETERS	APP TEST	CONDITIONS
FUNCTIONALLY STATIC	OUTPUT	OUTPUT ONE VOLTAGE FOR Q AND $\overline{Q}$	6	No load
		DRIVING CURRENT LOADED TO GROUND FOR Q AND $\overline{Q}$	7	Decrease load resistance until output voltage reaches 2.5 volts.
		DRIVING CURRENT LOADED TO + SUPPLY FOR Q AND $\overline{Q}$		No measurement
DYNAMIC	TRANSIENT	RISE, FALL, STORAGE, AND DELAY TIMES FOR Q AND $\overline{Q}$	8	Connect for binary counter - No load.
NONFUNCTIONAL		V_{SAT}	9	Apply 2.5 volts to Pin 2 and read the voltage at Pin 4.
		Power Supply Current	10	Connect an electrometer between Pin 1 and ground. Adjust V_{CC} to compensate for voltage drop across the electrometer.

ENGINEER: R. K. Thatcher DATE: 12/13/65

FIGURE 6. CHARACTERIZATION PLAN (FLIP-FLOPS-SHEET 2)

CHARACTERIZATION PLAN (AMPLIFIER)

CIRCUIT TYPE: A13251

BASIC CONDITIONS	NOTES
Pin 12 - 12 volts Pin 5 - ground Pin 6 - -12 Temperature - 77 F	

PARAMETER	APP TEST	CONDITIONS
Circuit Gain	1	Apply a 5 vpp signal through a 20 K and 2.2 ohm divider into amplifier. Record peak-peak output signal. Open loop.
Dynamic Output	1	Increase input signal until output signal goes into saturation record both positive and negative saturation levels. Open loop.
Bandwidth	2	Frequency at which amplifier output drops off 3 db. Open loop.
Input Common Mode Rejection Ratio	3	Amplifier tied down to a gain of 100. Input signal was 1.0 kc and 1.0 volts rms.
Input Bias Current	4	Input to ground-open loop configuration
Input Offset Voltage	5	Set up open loop; adjust input voltage until zero volts appears at the output. The voltage applied to the input is the offset voltage.
Resistance	6	Resistance between Pins 6 and 8. Also resistance between Pins 1 and 12.

FIGURE 7. CHARACTERIZATION PLAN (AMPLIFIERS-SHEET 1)

CIRCUIT TYPE: A13-251

PARAMETER	APP. TEST	CONDITIONS
NPN Transistor D-C Beta	7	A 1 milliampere collector current is set and the base current is measured.
PNP Transistor D-C Beta	8	A 1 milliampere collect current is set and the base current is measured.

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FIGURE 8. CHARACTERIZATION PLAN (AMPLIFIERS-SHEET 2)

which, because of their sensitive nature, required special measurement procedures. Permanent test set-ups, for example, had to be constructed.

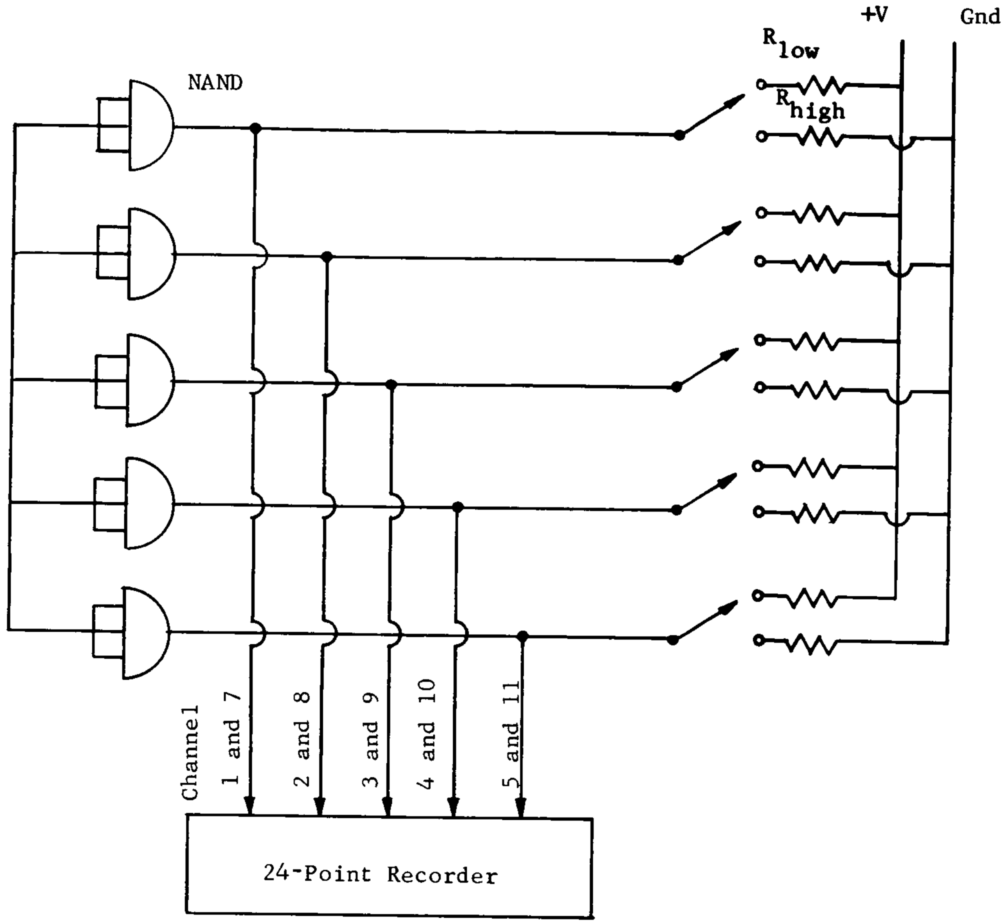
In two cases devices were inadvertently destroyed: In the 7531(MEM529) devices, all characterization had been completed and devices were being prepared for mounting on the test boards when it was discovered that six of them had become defective. How this occurred has never been discovered. All handling, storage, and operating precautions were observed. The other case, Motorola EPIC DTL devices, occurred after the devices were mounted on the test board. The static and dynamic circuits were being checked out when excess voltage was applied to the V_{CC} pin. In both cases the devices were replaced and the mounting continued.

Monitoring During Irradiation

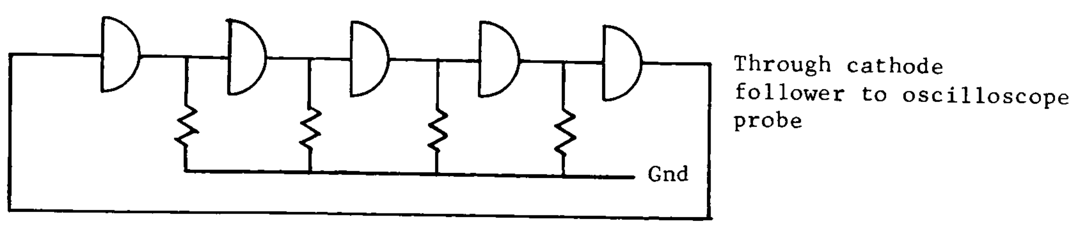
In situ monitoring was used to determine the mode of interaction between incident radiation and the microcircuits and the duration and degree of permanency of any deleterious effects that occurred. The number of parameters that could be measured during irradiation was limited by the physical problem of manipulating devices for specific tests. Therefore, a static test group was used to provide d-c characteristics and a dynamic group to provide a-c characteristics. The nonenergized group was monitored by periodic pulsed measurements.

Monitoring of NAND/NOR Gates

Figures 9a and 9b, in a most general manner, illustrate both the static and dynamic test configurations for the NAND/NOR gates. In the static configuration, the five circuits were operated in parallel with input



a. Static Configuration



b. Dynamic Configuration

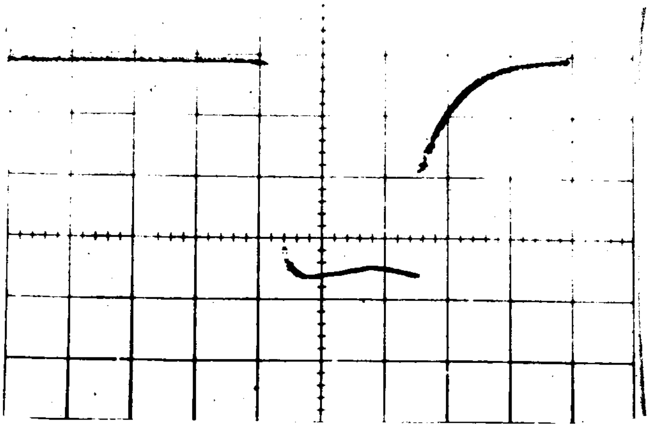
FIGURE 9. GENERAL TEST CONFIGURATIONS FOR NAND/NOR GATES

leads tied together to achieve an inverting function. The output voltage of each of the gates was recorded, in turn, by the use of a 24-point recorder. The first five channels of the recorder were used to record the "on" conditions. On the 6th and 18th channel switches were actuated, and the "off" condition prevailed. The "on" conditions were then reset on the 12th and 24th channel. Operating in this fashion one particular measurement was taken about every 24 seconds.

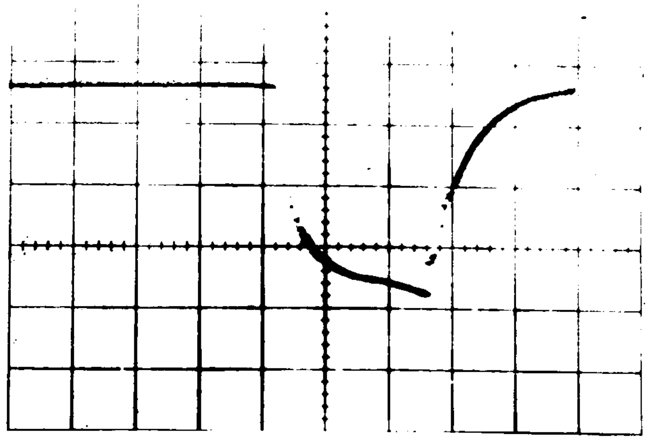
The resistor values selected for the two circuit conditions are dependent upon the characteristics of the logic configuration. For example, loading on the DTL configuration occurs when the output is low. In this case, the resistor for the low state was selected to simulate maximum fan-out, thereby allowing measurement of the saturation voltage characteristics of the output transistor. The high-state resistors generally were chosen to be comparable to the internal load resistor, allowing measurement of changes in the latter.

The power-supply voltages used were the same as those used during the characterization. The specific test configurations may be found in Appendix II according to device type.

The pulsed test (unbiased) units were connected in the same configuration as were the static units but were not biased during irradiation. However, periodically (every order of magnitude increase in fluence or whenever the machine was stopped) a pulsed bias and pulsed signal level were applied. The length of the pulses for the diffused gates was 3 microseconds and, for the MOS gates, 5 microseconds. For all gates only the low level was observed in this pulsed mode. Observation of the output voltage level was accomplished by the use of a Tektronix 564 storage oscilloscope and Polaroid camera. Because the circuits were in a static configuration and because only one output could be observed at a time, the pulsed circuits were pulsed five times during one set of pulsed measurements for a total of 15-40 microseconds of operation. Examples of pre- and post-photos of the types taken for this test are shown in Figure 10 for one amplifier and two gate circuits. Figure 10a is the output of Fairchild μM400. Figure 10b is the output of Motorola EPIC DTL and 10c is the output of Amelco A13251. The scales are listed below each picture. Figures 10b and 10c illustrate two problems encountered in obtaining responses in such a short period of time. The problem in 10b (preirradiation) is the fact that the low-level voltage is too small (<0.1 volt) to accurately measure and is limited by the equipment used. However, for the purpose of this experiment - looking for temporary changes in parameter values sufficiently large to cause failure - the equipment was adequate. It is interesting to note that the supply-voltage pulse and input-bias-level pulse were slightly out of synchronization and the high level output (V_{one}) appears toward the end of the pulse. The problem indicated in the preirradiation picture of 10c is the nearly insufficient pulse duration to allow for stabilization of the circuit. What has occurred in this picture is that the negative-supply-voltage pulse is slightly longer in duration than the positive-supply-voltage pulse and occurs slightly before the positive pulse. As a result the amplifier output goes first toward negative saturation and then toward positive saturation, the condition to which it is biased. It is interesting to note how the response of the amplifier changed between pre- and postirradiation pictures. After the exposure the amplifier appears to recover much more rapidly.

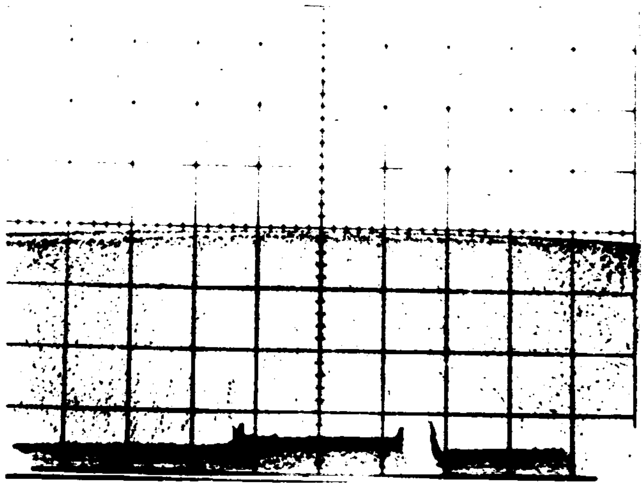


.9 v/cm
2 μsec/cm

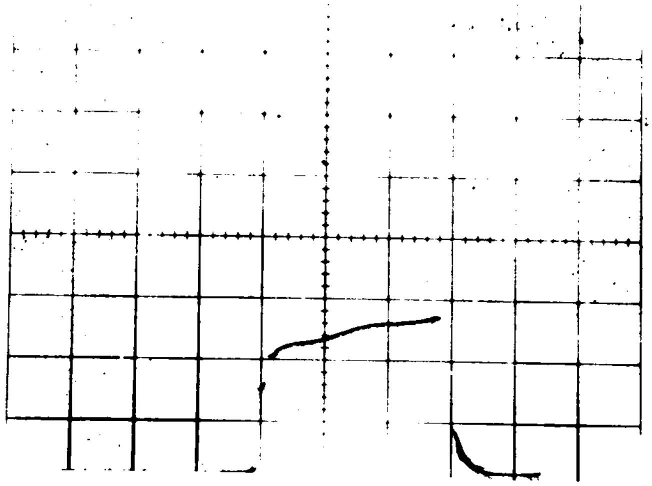


0.6 v/cm
2 μsec/cm

a. Fairchild μM400 device

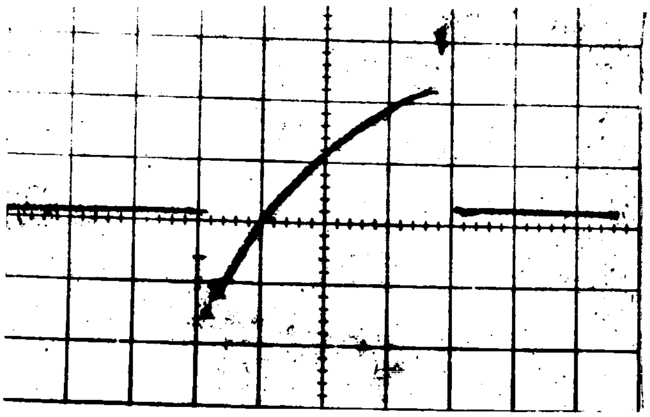


1.4 v/cm
1 μsec/cm

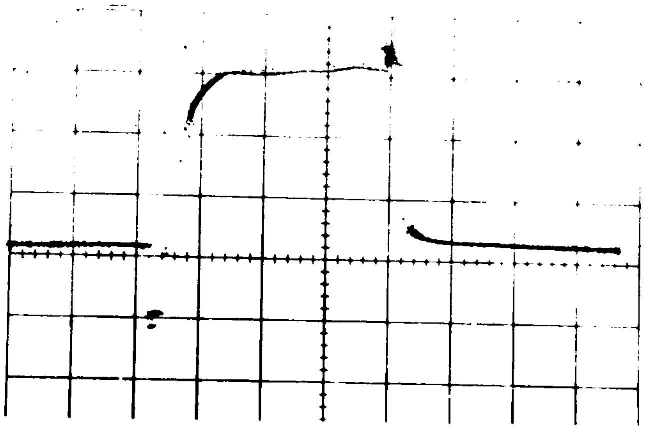


0.6 v/cm
1 μsec/cm

b. Motorola EPIC DTL device



3 v/cm
2 μsec/cm



1.6 v/cm
2 μsec/cm

c. Amelco A13251 device

FIGURE 10. PHOTOGRAPHS OF PULSED MEASUREMENT
Preirradiation state shown on the left,
postirradiation state shown on the right

Once the exposure was finished and the static circuit monitoring completed, the static circuits were disconnected from static monitoring circuitry. The pulsed samples were disconnected from their pulsed monitoring circuitry and connected to the static monitoring circuitry. These pulsed circuits were then operated in the static mode until it was felt that no significant change was occurring. These circuits were observed for as long as 15 minutes.

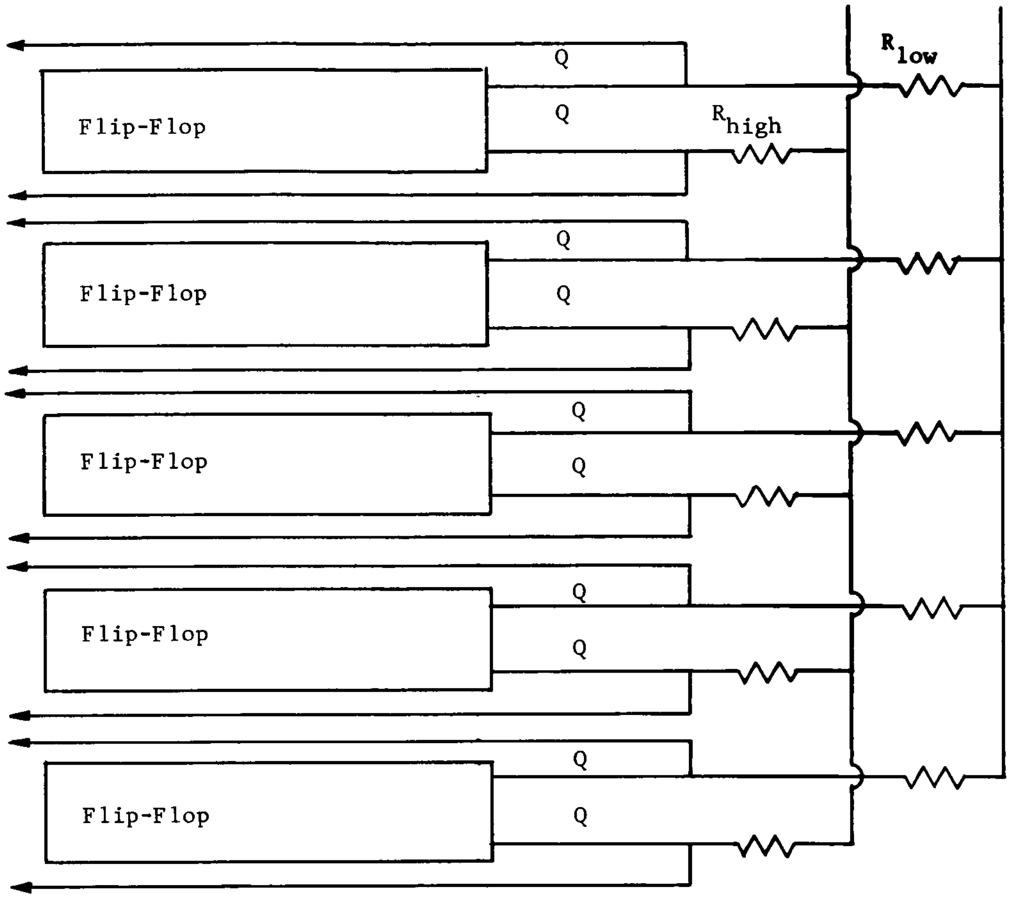
The general dynamic test configuration for the NAND/NOR gates is shown in Figure 9b. The gates are connected to form a ring oscillator under maximum fan-out with respect to worst-case conditions with the frequency of oscillation given by

$$f = \frac{1}{2N\tau_p}$$

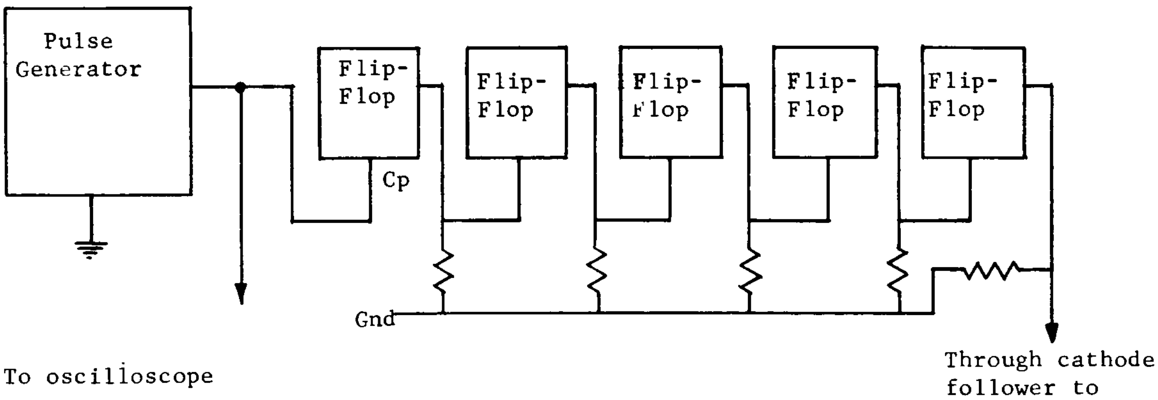
where N is the number of gates (five) and τ_p is the average propagation delay for a gate. Thus, by monitoring the frequency, changes in the time characteristics were continuously observed. The specific test configurations are given in Appendix II.

Monitoring of Flip-Flops

The general static and dynamic test configuration for the flip-flop functions are shown in Figure 11. In the static case both high- and low-state outputs were available, and no switching was required. The master switcher has been designed so that the flip flops in the static mode can be directly reset, thus keeping them in the same state. The fact that a flip-flop occasionally loses state during irradiation and can readily be reset to its proper state does not necessarily constitute a failure, since machine noise can change the flip-flop's state. However,



a. Static Configuration



b. Dynamic Configuration

FIGURE 11. GENERAL TEST CONFIGURATIONS FOR FLIP-FLOPS

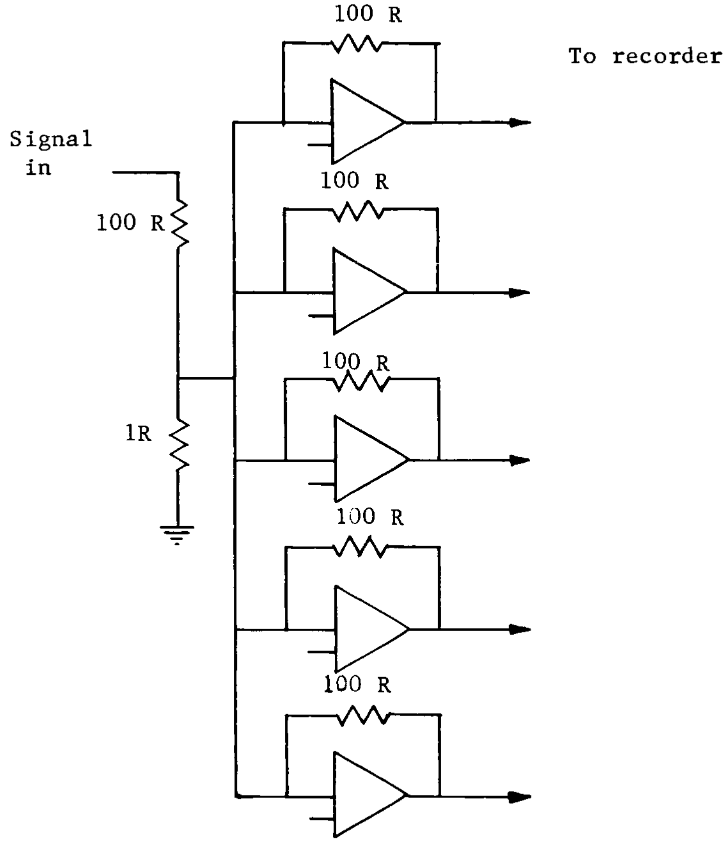
if the flip-flop has to be continuously reset, data and device characteristics should be examined to determine the responsible mechanisms. Generally when a flip-flop has to be continuously reset, it is considered a failure. Considerations similar to the gate case apply to the selection of these resistor values.

The pulsed-test configuration was the same as the static configuration and it was only operated periodically in a pulsed mode. The length of time for the pulses was 3 and 5 microseconds, respectively, for the diffused and MOS devices.

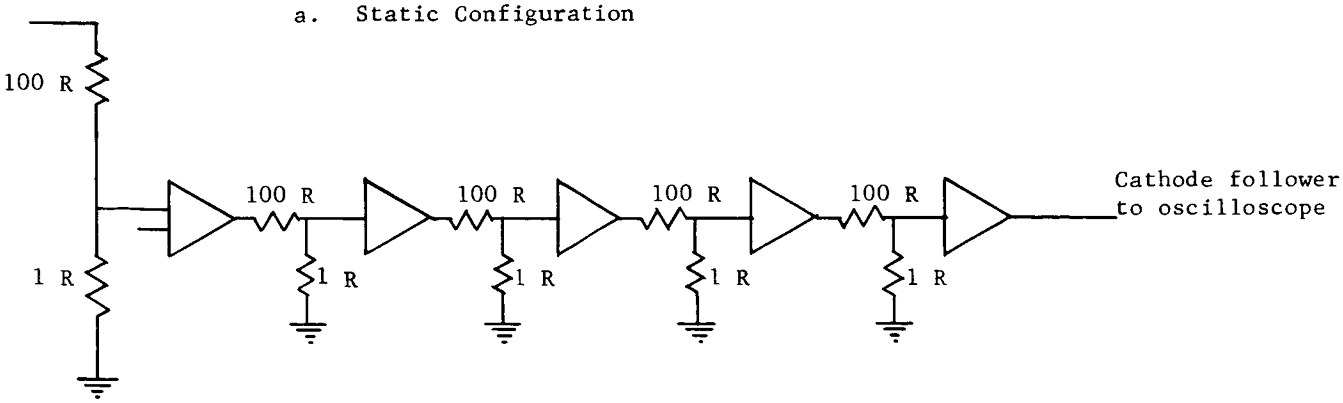
In the dynamic configuration, the flip-flops were connected in a ripple-counter configuration. With the five units shown, all counters would change state every 32nd count. Thus the propagation delay for all five units can be determined by measuring the delay between the 32nd clock-pulse input and the resultant fifth flip-flop output change. All devices were loaded for worst-case conditions.

Monitoring of Amplifiers

The general static configuration for the amplifiers is shown in Figure 12. The five amplifiers, each with a closed-loop gain of approximately 100, were operated in parallel with their input leads tied together. The outputs for Fairchild μA709 and Amelco A13251 devices had 1000-ohm loads attached, but Signetics SE505G was not loaded because of stability problems. This difference in loading would not appreciably affect the observed failure levels or failure modes of increased offset voltage and decreased open loop gain in the linear region. However, the



a. Static Configuration



b. Dynamic Configuration

FIGURE 12. GENERAL TEST CONFIGURATIONS FOR AMPLIFIERS

difference would affect the saturation voltage levels: The loading would decrease the maximum voltage swing. The output voltages for each amplifier were recorded in turn by use of the 24-point recorder. Four d-c levels were fed into the amplifiers sequentially. The first level was a voltage which would saturate negatively the output of the amplifiers. This was recorded on the first five channels of the recorder. During the sixth channel period the input was switched to the second d-c level, a small positive signal (+10 to +40 mv). The amplifier's output was then recorded on channels 7 through 11. The inputs were then switched to the third d-c level, a small negative signal (-10 to -40 mv), during the channel 12 period. These outputs were recorded on channels 13 through 17. During the channel 18 period, the inputs were switched to the fourth level, a large signal which saturated positively the amplifier's output, and these output levels were recorded on channels 19 through 23. The inputs were then returned to the first d-c level during the channel 24 period. From the recorded data it is possible to observe the changes in saturation voltages and gain, and also to observe indirectly the changes in offset voltage.

The pulsed-test configuration for the amplifiers was the same as the static configuration except that, while operating in a pulsed mode, an input voltage divider was added to the circuit. The reason for the extra divider was to limit the number of pulse generators necessary to make the measurement. The extra divider was removed before operation in the static mode was attempted. Also, none of the pulsed samples had loads on their outputs. During the pulsed measurements, the amplifiers were biased to a saturated output.

The general dynamic test configuration was a cascade of the amplifiers, that is, each amplifier had a closed-loop gain of about 100 and the output of the first amplifier was tied to the next amplifier through a 100:1 divider and so on through five devices. The output of the fifth device had no divider, but was fed directly through a cathode follower to an oscilloscope. The gain for the series of five devices was about 100. A sinusoidal signal, limited in magnitude so as to not saturate the output of any of the amplifiers, was the input into the amplifier series. Gain was the basic parameter observed in this configuration. General indications of other parameters (offset voltage and phase shift) could be observed. Specific test configurations for these devices are found in Appendix II, according to device type.

Radiation Monitoring Equipment

The equipment used for the monitoring of the devices is shown in Figure 13 as it appeared at the accelerator. From left to right on top of the tables are the 24-point recorder with the master switch box on top, the storage oscilloscope for recording pulsed measurements, two digital voltmeters with an auxiliary switch box on top, two pulse generators with a sinusoidal generator on top, an oscilloscope for observing the dynamic circuits with its Polaroid camera lying next to it and the recorder for recording ambient, static, radiated, and dynamic circuit temperatures. Below the first table are all the necessary power supplies and a third pulse generator. The master switch box was built during the first program and served a twofold purpose. First, in the case of gates and amplifiers it changed their state on every sixth count of the recorder; in the case of the flip-flops it connected the outputs to the proper pin of the

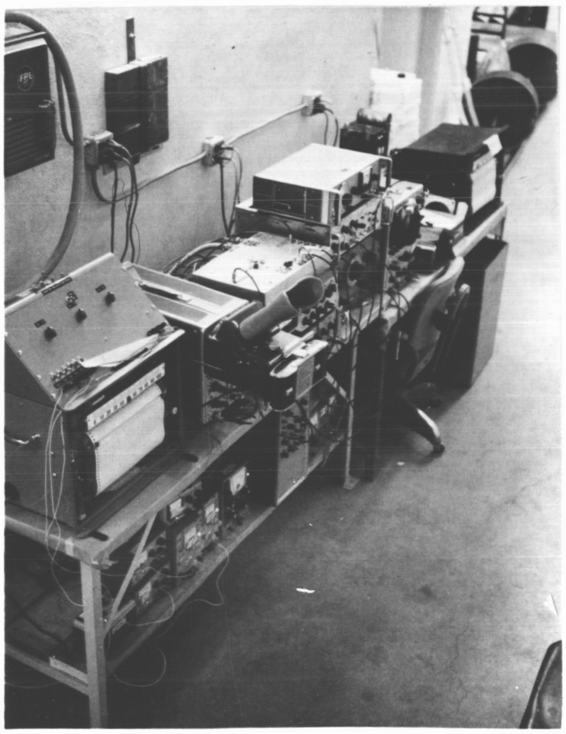
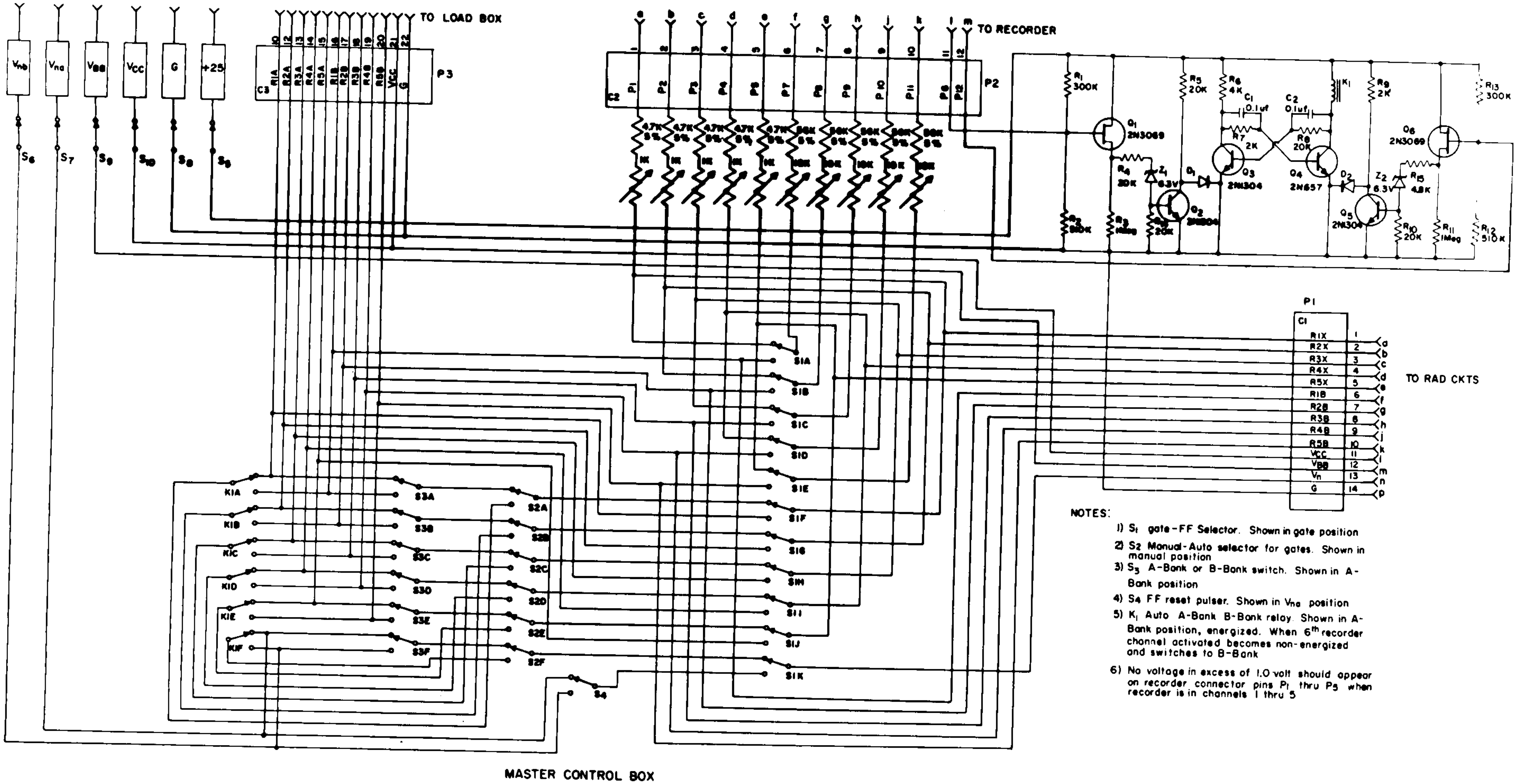


FIGURE 13. MONITORING EQUIPMENT IN SITE

recorder. Second, in the case of the gates it changed the load resistor every sixth count in sequence with the change in outputs; in the case of the flip-flops it connected the proper load resistor to the outputs of the device. The schematic of the master switcher is shown in Figure 14. The auxiliary switch box was built to facilitate the pulsed measurements, to control operation of static amplifier circuits, and to expediate switching the pulsed circuitry from the pulsed mode to the static operating mode. The general switching schematic of this box is shown in Figure 15.

Other Necessary Equipment

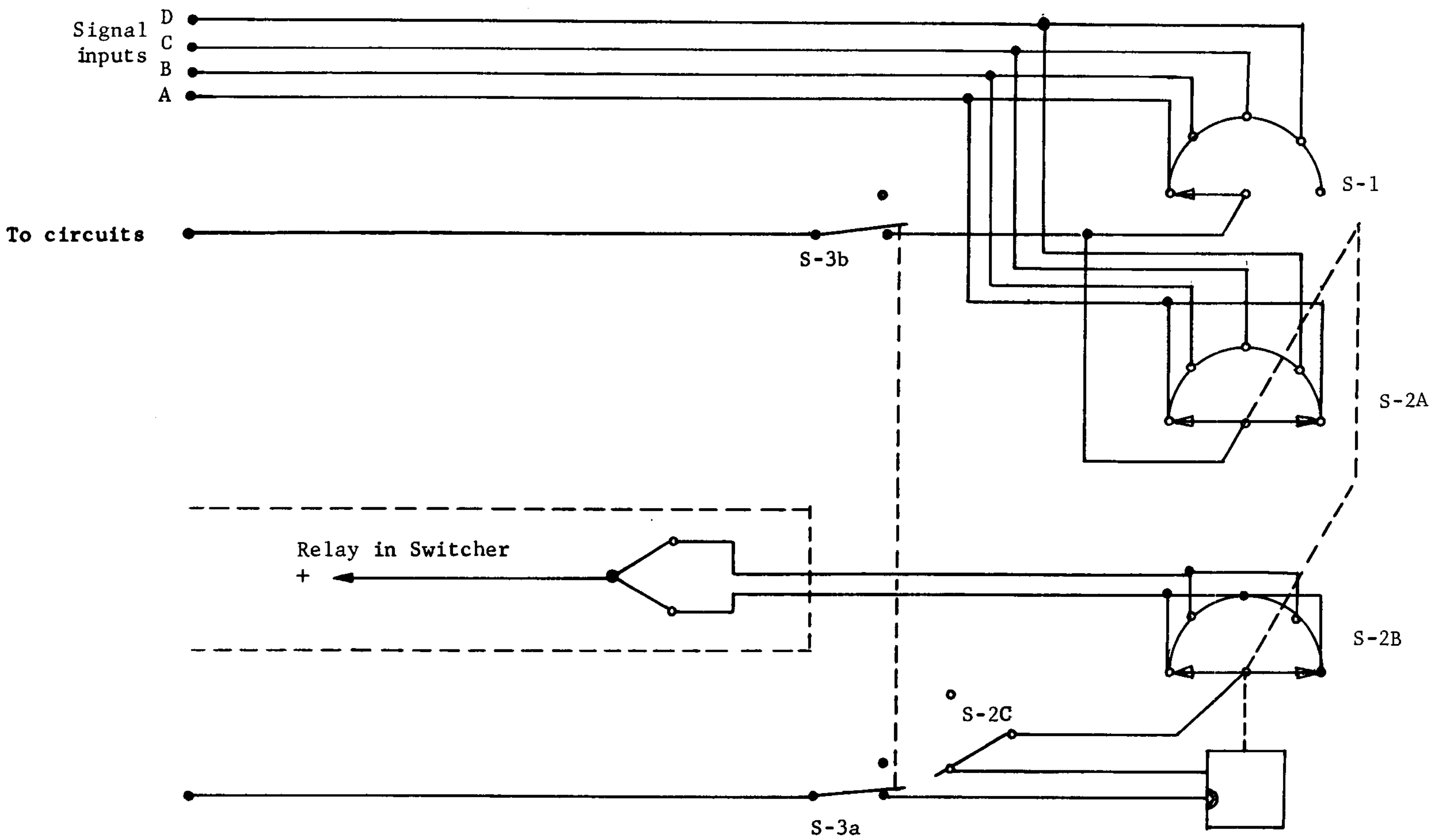
The other necessary equipment involved cabling which connected the circuits under test to the monitoring equipment, and the test jig for holding the specimens while in the radiation environment. The experimental set-up used three cables which were taken through flexible conduit to the circuits. One cable contained the output wires from the switch box to the circuits. The second cable contained four thermocouple leads, two coaxial cables, and two five-wire cables. The third contained miniature coaxial cables from the six cathode followers. The four thermocouples were used so that the ambient temperature and the temperature of the static, pulsed, and dynamic circuits could be monitored during the radiation exposure. Only the center device of the five in each operating condition was monitored. Two five-wire cables were needed to apply voltage to the cathode followers and operate relays when changing from the pulsed to the static mode ofoperation for the pulsed circuits. Cathode followers were used to bring all dynamic and pulsed signals out to the monitoring equipment. The circuit diagram for the cathode followers is shown in Figure 16.



NOTES:

1) S_1 gate-FF Selector. Shown in gate position
2) S_2 Manual-Auto selector for gates. Shown in manual position
3) S_3 A-Bank or B-Bank switch. Shown in A-Bank position
4) S_4 FF reset pulser. Shown in V_{na} position
5) K_1 Auto A-Bank B-Bank relay. Shown in A-Bank position, energized. When 6th recorder channel activated becomes non-energized and switches to B-Bank
6) No voltage in excess of 1.0 volt should appear on recorder connector pins P_1 thru P_5 when recorder is in channels 1 thru 5

FIGURE 14. SCHEMATIC OF MASTER SWITCHING CIRCUIT



Key:

S-1. Manual Signal Control

S-2A. Signal bank of stepper switch

S-2B. Coil control bank of stepper

S-2C. Stepper interpreter switch

S-3. On-off

FIGURE 15. SCHEMATIC FOR AUXILIARY SWITCHING CIRCUIT

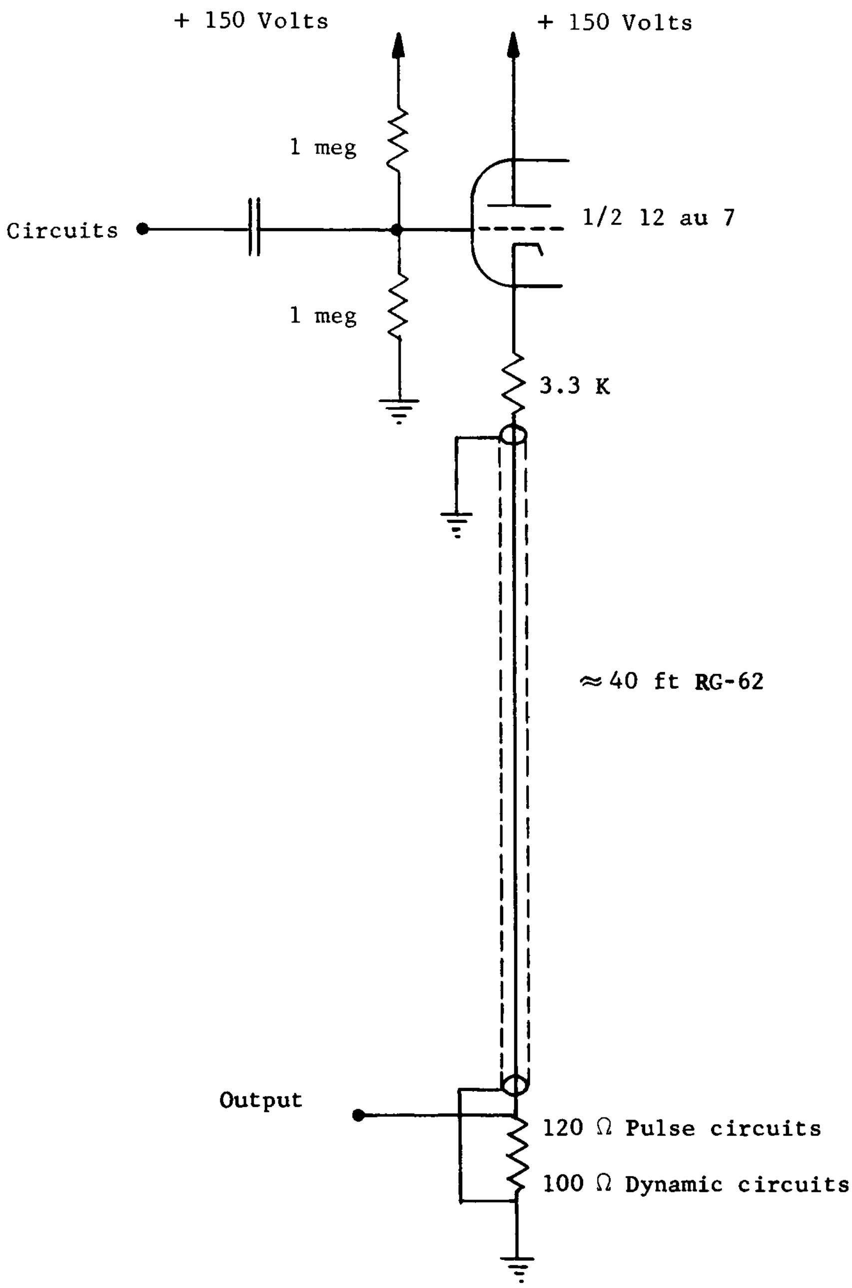
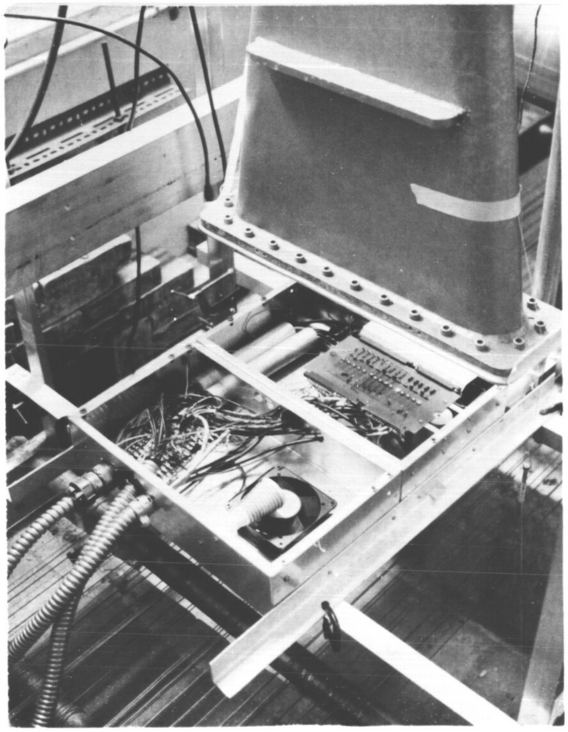


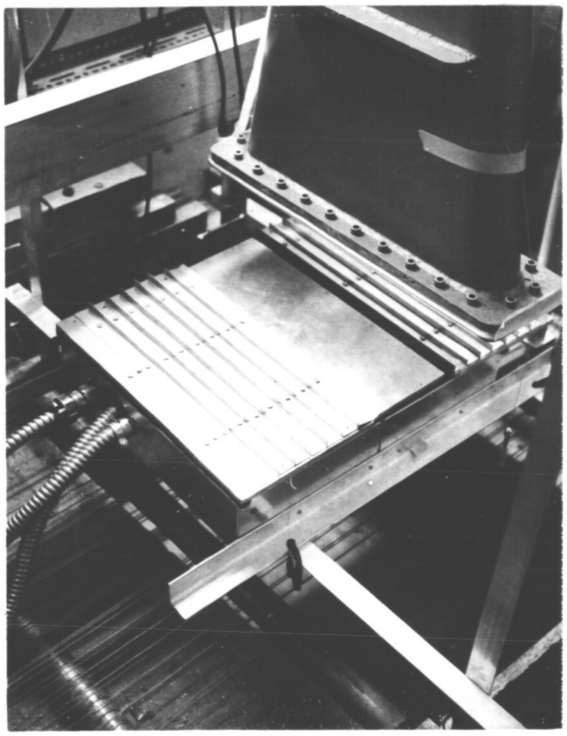
FIGURE 16. CATHODE FOLLOWER

The test jig consisted of two aluminum chassis lying side by side with their open ends up (Figure 17a). The chassis were held in position by an aluminum angle clamped to a metal frame below the bucket of the accelerator (Figure 17b). A braided battery cable connected the housing of the accelerator to the aluminum chassis as a common ground. Figure 17b clearly shows the covers for the chassis. The covers consist of soft 5/8-inch aluminum sheet onto which were bolted small aluminum angles to facilitate cooling. The contents of the test jig are easily recognizable in Figure 17a. In the one chassis are several terminal blocks, a cooling fan and a heater coil. The cathode followers (next to the test board and covered) and test board are located in the other chassis.

There was one test board for each device type. The board material was Panelyte Number 1615 with a slot down the center (slot for flat packs and holes for TO-5 cans) into which the devices were fitted. At the right-hand edge of the slot is a notch for access to the aperture of the Faraday cup. The test boards had one set circuit pattern etched on one side. This pattern allowed the devices to be welded to the boards and the proper voltages and outputs connected to the board through printed-circuit board connects. The interconnection between the circuits and the connectors were accomplished by additional wiring. Figures 18a and 18b show both sides of the Fairchild μA709 board. The wiring for the amplifiers was quite complex. The connectors on both sides of the board contained the same wiring, and, in this way, the need for many wires

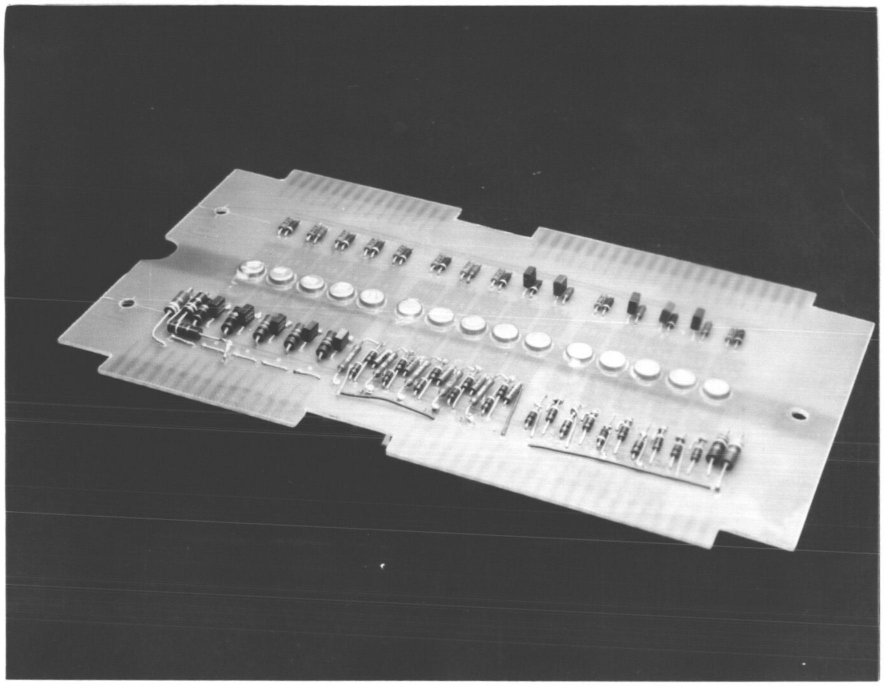


a. Aluminum Chassis

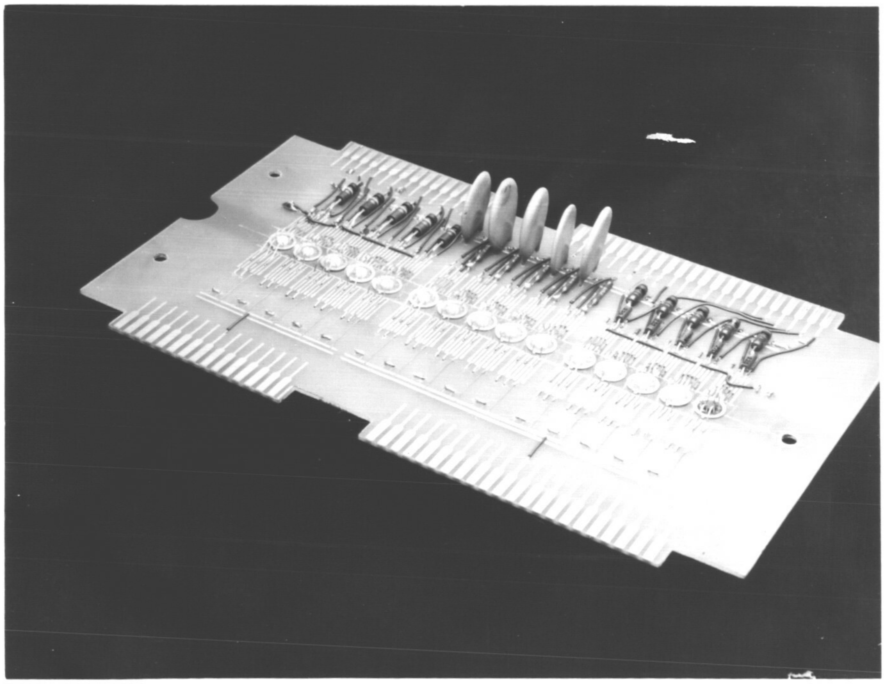


b. Aluminum Chassis with Cover

FIGURE 17. TEST JIG IN SITE



a. Top



b. Bottom

FIGURE 18. TEST BOARD FOR FAIRCHILD μA709

crossing back and forth through the electron beam was eliminated. Two crossovers were provided in the chassis and they can be seen at the left-hand side of the chassis. The crossovers were made from aluminum stock and had a wall thickness of 5/8 inch.

IRRADIATION PROCEDURE

The irradiation procedure generally followed the steps which had been outlined before the irradiations were started. Any deviations that occurred resulted from unexpected early microcircuit degradation. The procedure as set up was the following:

(1) Place device test boards in test jig

(2) Set all necessary voltages

(3) Observe operation of the pulsed circuits in the static operating mode through the monitoring equipment

(4) Convert pulsed circuits to pulsed operating mode and check operation

(5) Check static and dynamic circuit operation through monitoring equipment

(6) Take initial pulsed measurement pictures on radiated samples

(7) Start radiation at a flux of 10^{12} e/cm^2-sec for the digital devices other than those with MOS elements. The remaining devices were to have initial fluxes of 10^{11} e/cm^2-sec but after the first run this rate was lowered to 10^{10} e/cm^2-sec. The electron energy was 3-Mev except for the MOS devices. The electron energy for the MOS exposure was 1.5 Mev.

(8) Stop radiation after 50 seconds

(9) Make pulse measurements on pulsed circuits

(10) Start radiation at same flux

(11) Stop radiation after 50 seconds' more operation

(12) Make pulse measurements on pulsed circuits

(13) Start radiation at a flux one order of magnitude higher than before (10^{13} e/cm^2-sec for gates) if it appears as though no significant information will be lost by making the adjustment

(14) Stop radiation after 100 seconds (10^{15} e/cm^2 for gates)

(15) Make pulse measurements on pulsed circuits

(16) Start radiation at previous rate

(17) Stop radiation after 900 seconds (10^{16} e/cm^2 for gates)

(18) Make pulse measurements on pulsed circuits

(19) Start radiation at previous rate

(20) Stop radiation finally after 3600 seconds (5×10^{16} e/cm^2 for gates)

(21) Make pulse measurements on pulsed circuits

(22) Monitor the static and dynamic devices until they exhibit no more significant changes in characteristics

(23) After stabilization of the static and dynamic parts disconnect the dynamic and static parts from monitoring equipment

(24) Change the pulsed circuits from pulsed mode operation to static mode operation and connect to the static circuit's monitoring equipment

(25) Observe the pulsed circuits operating in the static mode up to fifteen minutes or until no significant changes are occuring

(26) Disconnect power supplies

(27) Remove test board from test jig

Any observations during the exposure which would be helpful in later analyses of the data were recorded, pictures were taken through the oscilloscope of the characteristics of the dynamically operating devices, and the statically operating device parameters were monitored. If during the radiation exposure a device appeared to be a failure the accelerator was shut off, pulsed measurements were taken, and the static and dynamic parameters observed for a few minutes. If the parameters quickly recovered, the test was continued. If the parameters did not recover, Step 22 was begun on our general outline of test procedures. The information obtained during this phase of the study is presented in Appendix III in the form of curves for the static parameters, data tables for the pulsed circuits, and pictures of waveforms for the dynamic circuits, along with the data sheets containing the pre- and post-characterization data for all 20 devices.

Problems During Irradiation

Two problems were confronted during the irradiation. First, the failures of some of the devices at relatively low fluences. Second, the inability to accurately measure fluence at low fluxes of the order of 10^9 e/cm^2-sec of below due to an instrumentation breakdown. The flux integrator (or counter) failed during the experiment. As a result the current to ground from the Faraday cup was monitored with an electrometer. The integration of flux was accomplished by keeping the Faraday-cup current constant (a very difficult job at low flux rates) and by keeping an accurate measure of the exposure time. As a result the flux had to be kept somewhat higher than would have been desirable to obtain a maximum amount of information on several of the circuit types.

Radiation Environment and Measurement

The radiation environment chosen for this program was produced by a Van de Graaff generator. The electron energy used for the portion of the program concerned with the non-MOS devices was 3 Mev. This value was chosen as a practical simulation of the electron-space radiation environment. The MOS devices were exposed to 1.5 Mev electrons. It was felt that the lower energy electrons may be more damaging from a surface standpoint than the 3 Mev electrons. The beam was approximately 1 centimeter wide and was swept through an arc of approximately 30 degrees. The beam was mapped along both the length and width using a Faraday cup, and the microcircuits were placed so as to receive equal exposures on all samples of a particular type.

The same Faraday cup used in mapping the electron beam was used for monitoring the radiation during exposure of the device. The actual exposure values for the devices are contained in the sections relating to the radiation effects on the respective devices.

The Faraday cup and the associated circuitry required for the above measurements of the radiation environment were built expressly for this program. A description of the circuit and cup follows.

Circuitry

The dosimetry considerations required a method of measurement to

(1) Provide cumulative radiation exposure with readout available at any time during the exposure and at completion

(2) Give a general indication of exposure rate with readout available during the exposure

(3) Assure that the radiation measurement and/or readout would not interrupt device exposure.

The circuitry designed to meet the foregoing requirements consisted of a conventional Faraday cup, a high-impedance amplifier and transistorized Schmitt trigger circuit, and an electromechanical counter with driver, as shown in Figure 19.

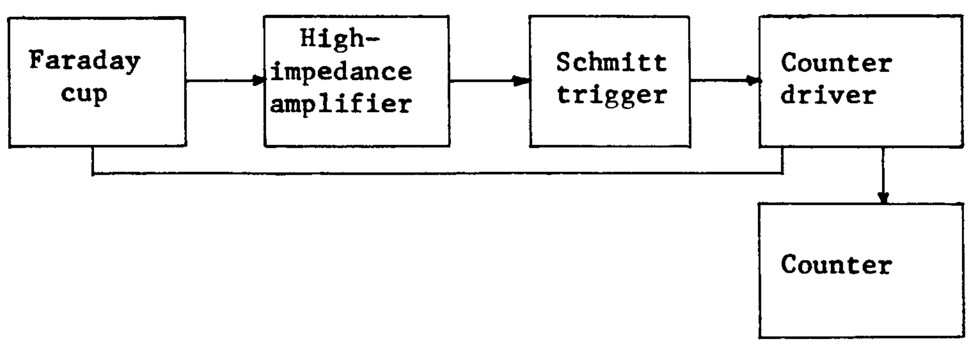


FIGURE 19. BLOCK DIAGRAM OF RADIATION MEASUREMENT CIRCUIT

However, the electronic portion of this system failed to operate properly during the experiment. It had been operated successfully many times in the laboratory prior to the experiment. Attempts at repair while at the test facilities were unsuccessful. As a consequence the fluence was calculated by continuously monitoring the current to ground from the Faraday cup and keeping an accurate account of the exposure time. To determine the flux, the current (in amperes) to ground from the Faraday cup was divided by the size of the orifice in the top of the Faraday cup and by the charge per electron. For example, a current of 1.6×10^{-9} ampere resulted in a flux given by

$$\frac{1.6 \times 10^{-9} \text{ ampere (coulomb/sec)}}{1 \times 10^{-1} \text{ cm}^2 \times 1.6 \times 10^{-19} \text{ (coulomb/electron)}} = 1 \times 10^{11} \text{ e/cm}^2\text{-sec}$$

One problem with this system could be loss of charge by leakage currents. However, in checking the equipment in the laboratory the leakage currents that were detected were too small to cause any appreciable error in the measurement. Possibly the largest single source of error was due to the fact that the flux could not be held absolutely constant, resulting in errors in our time integration of the flux. This error is estimated to be 3 percent.

Faraday Cup Description

Figure 20 is a schematic of the Faraday cup used during the experiment. Pertinent dimensions are included in the drawing. The cup was machined from aluminum and was insulated from the aluminum outer shell by alumina. The base and wall thicknesses of the cup were sufficient to stop all the electrons entering the opening. The net loss of electrons due to the effects of secondary emission is a function of the cup geometry and the material used. A high ratio of cup depth to cup diameter reduces the probability of secondary electrons escaping the cup. Aluminum was chosen

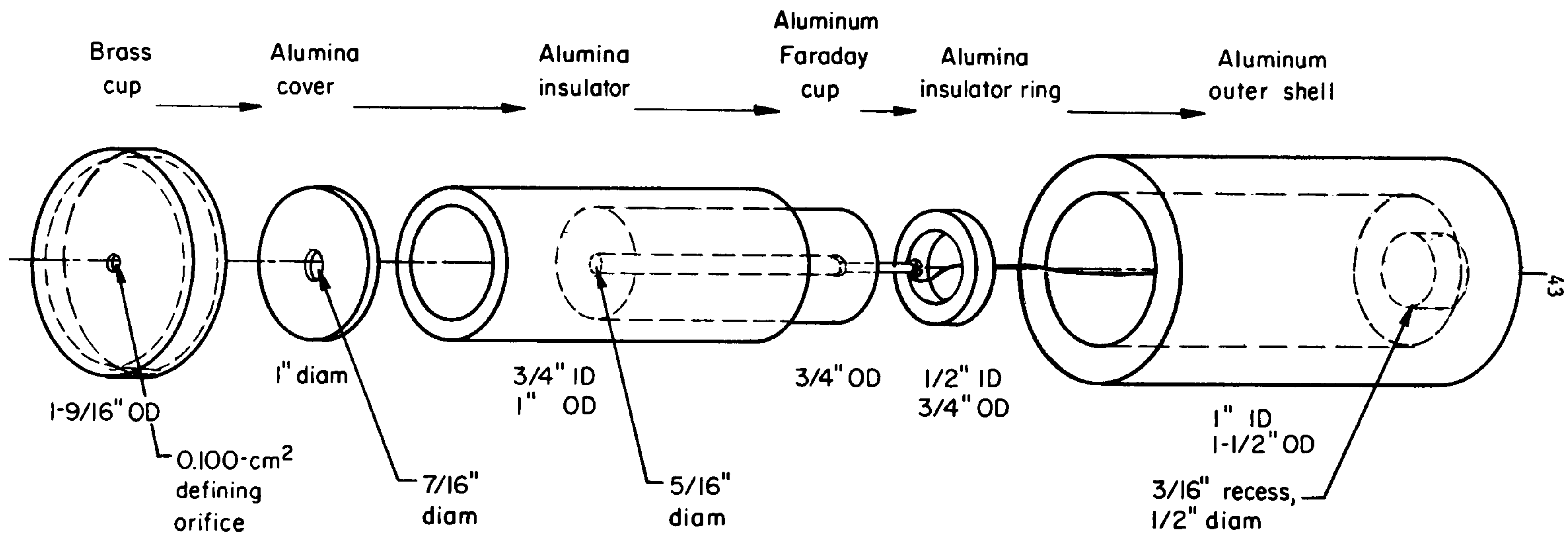


FIGURE 20. FARADAY CUP

as the cup material due to its excellent secondary-emission characteristics at the energies involved in the experiment.[4] Due to cup-design considerations, cup biasing was not deemed necessary.

The alumina insulator was made in three sections. The center section surrounded the sides and extended slightly beyond the bottom and top of the cup. The top section formed a cap between the center section and the defining orifice. The primary purpose of the top section of the insulator was to reduce the effects of air ionization between the defining orifice and the cup. The bottom section was similar to the top section but had a larger center hole. Its purpose was to insulate the cup from the grounded outer aluminum shell.

The brass top was thick enough to stopp all incident electrons with energies less than 3 Mev. A 0.100-cm^2 circular hole defined the sampling area. The cup was connected to the electrometer by approximately 40 feet of RG-62/U with the outer conductor connected to accelerator ground at the cup end. This cable was then placed in a 1-3/4-inch aluminum pipe with a wall thickness of 5/8 inch. The pipe ran from the cup to outside the accelerator. This pipe was also attached to accelerator ground.

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(4) "Back Scattering of Megavolt Electrons from Thick Targets", K. D. Wright and J. C. Trump, Journal of Applied Physics (February, 1962)

ANALYSIS OF DATA

The effects of 3 Mev electron radiation on eight microcircuit types and 1.5 Mev electron radiation on three MOS microcircuit types are summarized in tabular form in the next section. These effects are presented in terms of parametric device changes determined from both the in-situ measurements and the more comprehensive pre- and postirradiation measurements.

In this section the practical significance of the observed parametric changes are discussed. Attention is focused on salient features of the experimental results and on possible design steps to extend the period of device operation in the environment.

In the following analysis of part types it will be assumed that the reader is familiar (either through Battelle's 1965 report Contract No. NAS5 3985 or from other sources) with the basic damage mechanisms and the changes that occur in monolithic circuits when exposed to electron radiation. It will also be assumed that the parametric changes occurring in MOS transistors due to an electron irradiation are known. Where something is felt to be relatively new or possibly not widely known a reference is given.

Analysis Summary

Due to the variety of circuits in this program, it is difficult to discuss changes which are common to all four categories of circuits. However, one comment is appropriate before this discussion is broken down into the four categories. The point of failure in all categories has centered around the transistors. Whether it was transistors operating at very low current levels with leakage currents becoming an appreciable part of the current being controlled, or whether failures were due to increased gate threshold voltage or decreased gain resulting from surface or bulk damage, the problem device is the transistor. As a consequence, attempts at radiation hardening either by initial circuit design or by system design will have to be aimed at keeping the transistors or directly associated circuitry in operating ranges acceptable for satisfactory system operation.

Amplifier Circuitry

The mode of failure for the amplifiers was attributed to three basic parameter changes: decreased gain, increased input bias current, and increased offset voltage. Which parameter change or combination of changes will cause the first failure is not always easy to predict since it will depend not only on intrinsic device structure, but also on intrinsic circuit design and extrinsic device circuitry. Basically it was determined, as is explained in the analysis section, that these changes were, at least, initiated by surface damage. In some cases the changes occurred rapidly, and the nature of the monitoring measurements did not preclude the possibility that some of the observed changes were initiated by rate effects.

As far as actual use of amplifiers in a radiation environment is concerned, one can expect the input leakage current to increase, resulting in lower input impedance. For an operational amplifier, this could upset the feedback ratio unless a feedback network is chosen which has sufficiently low resistance to swamp the increased leakage. Fortunately, this effect opposes the reduction of transistor gain with radiation. Low balanced-input resistance from inputs to ground are also desirable to reduce the effect of increased leakage. That is, the voltage drop across a high- input resistor (resulting from a change in input leakage) will appear as a signal at the input, and may saturate the amplifier even though the input offset voltage inherent in the amplifier remains unchanged.

Input offset voltage is also likely to increase so that cascaded stages should, where possible, employ a-c rather than direct coupling to avoid saturating the latter stages. Where large output signals are required, it may be necessary to use strong feedback in order to make maximum use of the amplifier output swing capability while minimizing changes in offset voltage. Even with this precaution some safety factor should be used to allow for reduced output swing when the collector-emitter saturation voltage of the output transistors increases.

The μA709 amplifier experienced its first failure at less than 7×10^{11} e/cm^2. A statically operated amplifier exceeded the maximum allowable offset voltage of 7.5×10^{-3} volts. All other parameters appeared to not change or change insignificantly during and after the exposure.

The SE505G experienced first failure at 6×10^{13} e/cm^2 when the closed-loop gain decreased by more than 5 percent. The input bias current increased substantially from 109 to 132 percent. The offset voltage increased 13 to 56 percent and the saturation voltages did not change appreciably.

A decrease in closed-loop gain of greater than 5 percent also caused first failure in the A13-251 circuits. First failure occurred at an exposure of less than 10^{12} e/cm^2. Statistically significant changes in input offset voltage, resistance, transistor gain, amplifier gain, and bandwidth were noted. No statistically significant differences were observed in amplifier saturation voltage, input bias current or common mode rejection ratio.

Important parametric changes in these amplifiers are compiled in Table 2.

Micropower Circuitry

The principal mode of failure in these devices was transistor degradation with decreases in gain and increases in V_{SAT} and V_{BEon}. The changes in these parameters can be attributed not only to bulk, but also to surface damage. The input drive current, input threshold voltages, the output drive current, and the output low-level voltages generally increased. The high-level output voltage showed decreases, with the Westinghouse WS113Q unit showing the largest decrease because it is controlled by the saturation voltage of transistor. The rise, fall, and delay times showed increases while the storage time showed slight decreases. The changes are consistent with the changes observed in last year's NASA program.

The first failure for the PL987 circuits occurred at a fluence of 1.45×10^{15} e/cm^2. The failure was caused by a circuit exceeding its maximum specified V_{ZERO} output voltage level of 0.215 volts.

TABLE 2. COMPARATIVE PARAMETRIC CHANGES IN PERCENT FOR AMPLIFIER CIRCUITS*

Description	μA709	SE505G	A13 251
Fluence to First Failure, e/cm^2	7×10^{11}	6×10^{13}	$<10^{12}$
Total Fluence	7.6×10^{12}	4.3×10^{14}	3.7×10^{14}
Open-Loop Gain	-8.9	-27.3	-33.4
Positive Saturation	1.7	-.8 and 4.6	0.0
Negative Saturation	-.7 and 5.9	7.1	0.0
Bandwidth	4.7	46.5	182.
Input Bias Current	57.2	109.	370.
Offset Voltage	173.	131.	34.9
Common Mode Rejection Ratio	-3.4	-1.0	---
Distortion	---	-5.9	9.5
DC Balance Output	---	-3.2	---
Resistance	---	6.1	9.6
Transistor Gain NPN	---	---	-49.3
PNP	---	---	-96.2

Note: N.S. = No significant change
--- = Data not taken or data inconclusive

*These data are percent average changes only in the static group.

The first failure for the WS113 was caused by a circuit exceeding the minimum specified V_{one} output voltage level of 2.50 volts. This first failure occurred at 8.0×10^{14} e/cm^2.

A comparison of important parametric changes for these two circuit types is given in Table 3.

MOS Digital Circuitry

The failure modes, changes in V_{zero} and V_{one} voltage levels, can be attributed to increases in gate-threshold voltage and drain-to-source leakage current. The gate-threshold voltages increased from 7 to 55 percent. leakage current was measured for one device type which indicated a maximum current of 10^{-7} ampere. Other sources[5&6] indicated, however, that leakage currents could occur as high as 10^{-5} ampere. A current of this magnitude would be sufficiently large to cause the 2 to 9-volt drops observed in the output high-level voltage. The transient parameters all showed increases which ranged from 7 to 228 percent. These transient parameters will be affected by relative changes in parameters such as resistance and capacitance external to the transistor as well as internal changes. Changes in fan-out may or may not affect the period of operation in the radiation environment, depending upon which output level causes the device failure. Failure of the high level may be effected by changes in load, depending on magnitude of the loads and the apparent magnitude of drain-to-source resistance of the transistor used as a pull-up resistor.

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(5) Stanley, Alan G., "Comparison of MOS and Metal-Nitride-Semiconductor Insulated Gate Field Effect Transistors Under Electron Irradiation", presented at Annual Conference on Nuclear and Space Radiation Effects, Stanford University, Palo Alto, California (July 18-22, 1966).

(6) Gordon, Frederick, Jr. and Wannemacher, Harry E., Jr., "The Effects of Space Radiation on MOSFET Devices and Some Implications of Those Effects" X-716-66-347, Goddard Space Flight Center, Greenbelt, Maryland (August,1966).

TABLE 3. COMPARATIVE PARAMETRIC CHANGES IN PERCENT FOR MICROPOWER CIRCUITS*

Description	PL987	WS113Q
Fluence to First Failure, e/cm^2	1.45×10^{15}	8.0×10^{14}
Total Fluence	1.45×10^{15}	9.4×10^{14}
Input Voltage Threshold	~5.0	23.5
Input Drive Current	-2.8	N.S.
Input Leakage Current	-19.2	N.S.
Power Supply Current	N.S.	-14.5
Output Drive Current	-42.7	---
Resistance	2.3	---
Rise Time	39.1	24.3
Fall Time	8.0	183.
Delay Time	21.5	-6.7
Storage Time	-2.3	-10.3
Output One Level	---	-6.4 and -24.7
Output Saturation Voltage	---	708. to 914.

Note: N.S. = No significant change
--- = Data not taken or data inconclusive

*These data are percent average changes only in the static group.

First failure for the 7532 circuits occurred at 2.5×10^{12} e/cm^2 and was caused by both output voltage levels exceeding their specified voltage limits.

The 7531 failure was a result of a decrease in high level output voltage to less than its specified value. The first failure occurred at less than 1.2×10^{11} e/cm^2.

The μM400 experienced first failure at less than 1.2×10^{11} e/cm^2. The failure was a result of a circuit exceeding a predetermined level for the output V_{zero} voltage.

Important parametric changes are compared for these three circuit types in Table 4.

Dielectrically Isolated Circuitry

The changes observed for these devices were quite similar to the ones observed for monolithic circuits in the 1965 program. Under this environment, the degradation of transistor gain is the major factor in their radiation resistance. There were no unusual changes or nonchanges which might be directly attributed to the use of the dielectric isolation.

Exceeding the specified V_{zero} output voltage caused the RD210 circuits to experience first failure at 4.15×10^{14} e/cm^2.

The DTL gates by Motorola (DTL EPIC and MC962) experienced first failure at 3.88×10^{15} e/cm^2. The failure was caused by the V_{zero} output voltage level exceeding its specified limit.

Table 5 compares some of the important parametric changes for these circuit types.

TABLE 4. COMPARATIVE PARAMETRIC CHANGES IN PERCENT FOR MOS CIRCUITS*

Description	7532	7531 (MEM529)	μM400
Fluence to First Failure, e/cm^2	$<2.5 \times 10^{12}$	$<1.2 \times 10^{11}$	$<1.2 \times 10^{11}$
Total Fluence	5×10^{12}	1×10^{12}	2.5×10^{11}
Transconductance	-6.7	---	-21.8
Dynamic Drain Resistance	N.S.	---	34.
"On" Drain Current	-61.5	---	-50.3
Input Voltage Thresholds	9 to 30.	-25.2 (clocked)	38.9
Output One Level	-32.	-55.	---
Output Zero Level	17.8	---	---
Output Drive Current	-84.9	---	---
Rise Time	229.	---	---
Fall Time	176.	---	---
Delay Time	131.	---	---
Storage Time	80.7	---	---
Gate to Body Capacitance	---	---	N.S.
Gate to Drain Capacitance	---	---	N.S.
Gate to Source Capacitance	---	---	N.S.
Drain Leakage Current	---	---	1.2×10^5
Gate Leakage	---	---	626.

Note: N.S. = No significant change
--- = Data not taken or data inconclusive

*These data are percent average changes only in the static group.

TABLE 5. COMPARATIVE PARAMETRIC CHANGES IN PERCENT FOR DIELECTRICALLY ISOLATED CIRCUITS*

Description	RD-210	EPIC-DTL	MC962
Fluence to First Failure, e/cm^2	4.15×10^{14}	3.88×10^{15}	3.88×10^{15}
Total Fluence	4.6×10^{14}	3.94×10^{15}	3.94×10^{15}
Input Voltage Threshold	-3.5	3 to 11	N.S.
Input Drive Current	N.S.	N.S.	N.S.
Input Leakage Current	N.S.	N.S.	N.S.
Output Drive Current	-13.6	-79.0	---
Output Saturation Voltage	11.3	---	---
Rise Time	9.9	---	---
Fall Time	N.S.	---	---
Delay Time	N.S.	---	---
Storage Time	N.S.	---	---
Forward Diode Voltage	N.S.	---	---
Resistance	N.S.	N.S.	N.S.
Gain	-42.3	---	---

Note: N.S. = No significant change
--- = Data not taken or data inconclusive

*These data are percent average changes only in the dynamic group.

Description of Data Summaries

To help clarify the detailed analysis and make it easier to follow, a discussion on the format for the presentation of the summarized data in the "Results" section is presented below.

Circuit Identification

The first page of each summary identifies the circuit. Included on this page is the Circuit Identification Code, the Circuit Diagram, and a Circuit Description. The latter describes the function, process, and advertised speed. In the case of gates, the advertised speed is in terms of average propagation delay. For clocked flip-flops, it is in terms of the maximum clock frequency. The amplifiers are described by their advertised gain.

In-Situ Data

The second page of each summary presents the results of data taken with the microcircuits in radiation test configurations. Included is the radiation exposure accumulated at the point of first failure, the total exposure, the failure mode, and information pertaining to the parameters that were monitored during the irradiation. The monitored parameters for digital circuits are

(1) The low-level voltage (V_{zero}) at the output of the circuits in the static test group. These voltages are worst case with respect to input voltages and output loading. This was done in order that the data would be

representative of all possible design options and to obtain noncatastrophic failures for purposes of successful recharacterization.

(2) The high-level voltage (V_{one}) at the output of the circuits in the static test group. The voltages are again worst case with respect to input voltages.

(3) Pulsed measurement of V_{zero} for the circuits in the pulsed test group. Once the exposure was finished, the pulsed circuits were operated and monitored with the static monitoring equipment. The resulting parameter values are listed under the pulsed circuits and called "Static Mode" parameters.

(4) The total series propagation delay (Multistage Propagation Delay) of the circuits in the dynamic test group. For gates the reciprocal frequency of a ring oscillator was used; this is twice the average series propagation delay of the gates. For clocked flip-flops the total delay through a ripple counter was used as the time parameter. These circuits were also worst case, loaded to make their changes more compatible with the static circuit results.

The monitored parameters for the amplifier circuits are

(1) The positive and negative saturation voltages

(2) A small d-c positive and negative input signal monitored at the output of the static units. This series of two d-c signals allows the gain of the amplifier to be calculated and the change in offset voltage to be observed.

(3) A pulsed measurement of the output saturation voltage mode on the pulsed test group. The pulsed circuits were operated after the exposure and monitored with the static monitoring equipment. The parameters obtained in this manner are listed under the pulsed circuits and indicated by calling them "Static Mode" parameters.

(4) The average change in gain of the circuits in the dynamic test group. For μA709 and A13251 the change will be the change in open loop gain, but for SE505G the change will be for closed loop gain.

The parameter values at four points in the test sequence are compared. These points are

(1) Initial (just prior to irradiation)

(2) Final (just prior to termination of irradiation)

(3) Post Rad. In Site (following irradiation, after parameters stabilize)

(4) Post Rad. 1 Week (approximately one week after irradiation).

The temperature of the microcircuit packages, as determined from thermocouple measurements, is given for each of the four points.

For the static and pulsed test group parameters the mean values, the percent change of the mean values, and the minimum and maximum readings obtained from the five circuits are listed. For the dynamic circuits the monitored parameter and its percent change are listed.

Characterization Data

The third and following pages of each summary contain a comparative tabular evaluation of the pre- and postcharacterization measurements. The radiation-induced device parametric changes may be read directly from the tables. The data for one parameter are presented and partially analyzed in one column. Since the data were summarized by computer, the number of columns (or parameters) may vary from one to four on a page, depending on how many columns of raw data were combined. At the top of each column is listed the parameter. In order to make circuit-by-circuit comparisons convenient, a common symbology is used throughout the summaries. The symbols to a limited extent are consistent with those used in industry to denote microcircuit parameters. The symbols are limited because the computer only prints capital Arabic letters and no subscripts. The symbols also do not necessarily correspond to those used in the specific characterization plans of Appendix I which more closely follow the industrial type symbol. Listed immediately before the summarized results are the common symbols and an explanation of the parameter. Below the parameter symbol on the data sheet are located the units of measure for that parameter. Below the units the information is broken down into six groupings: the information pertaining specifically to the pulsed, dynamic, static, and control groups; the F-test value; and the t-test values for the six possible binary combinations of the groups. The parameter changes, as indicated, are considered separately for each test group to permit necessary comparisons. The effects of the electrical condition during irradiation are basically of interest, as are the changes in the nonirradiated control group (due to differences in test conditions, measurement variability, damaging tests, etc.) in relation to the changes in the irradiated test group. The following test group code is used:

P... pulsed test group (irradiated and nonenergized except during measurements)

D... dynamic test group (irradiated)

S... static test group (irradiated)

C... control group (not irradiated)

For each test group the following summarized information is provided:

(1) Number of data points considered in the mathematical analysis except for calculation of the initial mean

(2) Initial mean of the precharacterization values for devices belonging to that particular test group

(3) Average change between pre- and postcharacterization parameter values for the devices belonging to that particular test group

(4) Standard deviation (STD) of the mean is a measure of the spread in parameter changes of the sample remaining in a particular test group

(5) Average percent change is the average of the individual percent changes in parameter values for each of the samples within a particular test group. These data are thus "normalized" to fractional changes from initial instead of absolute changes

(6) Interval estimate as percent is an estimate of the average change that might be seen for this parameter if additional samples were exposured to the same electron environment under the same test conditions. It should be realized that this estimate is based on the number of samples within a particular

test group and on a predetermined confidence level. For this program, a 95-percent confidence level has been used. To summarize this in semi-empirical form the interval estimate as a percent is the

Probability [X < percent average change < Y] = .95,

where X and Y are the limits of the interval expressed as a percent.

(7) Percent average (AVE) change is the average change in parameter values expressed as a percent of the initial value. This value should fall within the interval estimate when expressed as a percent. It is not necessarily true, however, that the average percent change will fall within the interval estimate when it is expressed as a percent.

Below the information for each individual test group there are the results obtained from performing an F-test and a series of t-tests.

The F-test as used here provides sufficient information to either accept or reject the hypothesis that the electron irradiation has not caused a significant change in a particular parameter value. This information is provided in the form of an F-value which is computed from the parameter data experimentally obtained from all the samples. This hypothesis can be checked at any desired confidence level by referring to a standard F-table. The F-table is entered by selecting the desired confidence level and determining the degrees of freedom (for this case three and the number of samples used minus four). If the F-value obtained in this manner from the standard F-table is less than the computed F-value reported in the data summaries, the hypothesis is rejected at the selected confidence level.

To clarify the use of the F-test consider the F-values presented on page 102 for the Signetics SE505G concerning parameter measurements of input bias current, gain, and resistance. Looking at the data summary sheets, one can see that 20 samples were used in this mathematical analysis. Select a degree of confidence, say 95 percent. Locate an F-table which is for a 95 percent confidence level. A reference for this is the <u>Handbook of Probability and Statistics with Tables</u> by Burington and May, reprinted 1958, page 278. To enter this F-table look for the F-value under the column headed by 3 and in the row listed as 16 (3 and 20 - 4 = 16 are the degrees of freedom). The number is 3.24. Now compare 3.24 with the F-value reported on the data summary sheet for the input bias current of the Signetics SE505G. It is seen that the computed F-value, 173.4, is greater than the tabulated F-value, 3.24, and hence we can reject the hypothesis that the electron irradiation has not caused a significant change in the input bias current.

In other words we are 95 percent confident that, if units comparable to the ones used for this program are exposed to a 3 Mev electron flux for a total exposure of 4.3×10^{14} e/cm^2, then a statistically significant change will occur in the input bias current due to the radiation.

Looking at the F-value reported for the resistance measured between pins 1 and 2 it is seen that the tabulated F-value, 3.24, is greater than the computed F-value, 1.590, and hence the hypothesis would be accepted. That is, we are 95 percent confident that, if units comparable to the ones used in this program were exposed to an environment like the one for this experiment, then no statistically significant change would occur in the resistance values.

The <u>t-test</u> as used here provides sufficient information to accept or reject the hypothesis that test groups being considered are not significantly different as a result of their exposure to the electron environment. This information is provided in the form of a t-value which is computed from the parameter data experimentally obtained from the samples being considered. This hypothesis also can be checked at any desired confidence level. Checking the hypothesis with the t-test is similar to that of the F-test. Select a confidence level and determine the degrees of freedom (for this case the number of samples considered minus two). With this information locate the t-value in a standard t-table. If the located t-value is less than the computed t-value reported in the summaries then the hypothesis is rejected at the selected confidence level.

To illustrate the use of the t-test again refer to the Signetics SE505G data summary sheet for input bias current, gain, and resistance, page 102. For this particular case the mathematical analysis for each group contained five samples. This fact makes the t-value analysis convenient but one must be careful in other cases because the number of samples per group does vary. Since there are five samples per group and two groups are considered, there are 10 minus 2 or 8 degrees of freedom. Now select a confidence level, say 99 percent. Usually the t-test is performed at a higher confidence level than the F-test. Locate a t-table or use the one on page 283 of the <u>Handbook of Probability and Statistics with Tables</u> which is referenced under the F-test discussion. Looking under the column headed by 0.01 (1.00 minus 0.99) and in the row listed as 8 find the t-value 3.355. Compare this value with those reported on the data summary sheet. For the input bias current for the Signetics SE505G, it can be seen that the computed t-value for the P-C (19.97), D-C (18.45), and S-c (16.95) groups are greater than the tabulated t-value. As a result we can reject at the 99 percent confidence level the hypothesis that the pulsed (P), dynamic (D), and Static (S) groups each do differ by a statistically significant amount from the control (C) group as a result of their exposure to the electron environment.

In other words we can say with 99 percent confidence that units comparable to those used in this program, when exposed to an environment like the one used on the Signetics SE505G units, will show a statistically significant difference between the control group and each of the other groups, pulsed, dynamic and static, as a result of the environment.

Further checking of the standard t-value against the computed t-values for the input bias current for the P-D, P-S, and D-S groupings indicates that we can accept the hypotheses at the 99 percent confidence level. It should be realized that these are independent checks and that because one group shows a significant difference between itself and another group has no bearing on what can be expected for any of the other five groupings.

It should also be noted that both the F- and t-tests only allow their respective hypothesis to be checked for acceptance or rejection at a specified confidence level and nothing more than that can be said based on the results of such tests.

Analysis of Test Data for the Amplifier Circuits

In the analysis that follows, reference is made to the tabulated results appearing in the following "Results" section.

The failure criterion for this program was any parameter exceeding the limit specified by the manufacturer. Failure limits were specified in this manner to be compatible with the information presently supplied to design engineers by the manufacturers. For the amplifiers, however, it was arbitrarily determined that a 5 percent decrease in closed loop gain would be considered a failure.

Fairchild μA709

Fairchild's μA709 is an operational amplifier having a nominal open-loop gain of 32,000. These circuits are of the planar epitaxial construction.

The first failure occurred at an electron fluence less than 7×10^{11} e/cm^2. Total fluence received by these devices was 7.6×10^{12} e/cm^2 at a flux of 10^{10} e/cm^2-sec. The first failure was a statically operated amplifier that exceeded the maximum allowable offset voltage of 7.5×10^{-3} volts. The same behavior, a tendency toward negative saturation, was noted in the four remaining amplifiers of this group. The closed-loop amplifier gain during the exposure, however, appeared to remain unchanged. In view of this and the fact that the amplifiers had recovered significantly in the few minutes following the first exposure (total fluence 1.9×10^{12} e/cm^2), a second exposure was made. Several seconds after initiating this exposure, all but two of the amplifiers had completely saturated (negatively) and the exposure was promptly terminated. Total fluence for the first and second exposures amounted to 2.6×10^{12} e/cm^2. Some 5 minutes later, all amplifiers of the static group had recovered from saturation. It is interesting to note that, when the pulsed group was operated in the static mode following the second exposure, operation of the entire group was normal and within specifications.

Because no indications of failure were evident other than output drift of the static and dynamic groups, the devices were exposed a third time until a total fluence of 7.6×10^{12} e/cm^2 was attained and all but one of the static circuits had saturated outputs. This effect was so strong that even with a signal of +200 mv (and a gain of 100) at the non-inverting input, four of the five statically operated circuits were saturated negatively. Eight minutes following the last exposure, three out of five circuits were recovering toward normal values. Recovery occurred rapidly for the first minute or less, and thereafter proceeded with a time constant of 20 minutes or longer. Pulsed circuits were operated in the static mode a second time following the last exposure. No change had occurred in any of these units; all remained within the limits given in the specification sheet. It should be noted that the specification sheet used for testing and failure criterion was only tentative and differs in some respects from the present μA709 data sheet.

Seven parameters of the μA709 were measured at Battelle in the pre- and postirradiation characterization. The results of the analysis done on these data indicate that there were no significant permanent changes which could be attributed to the radiation. While some minor changes have occurred, one cannot draw any conclusions because of large variations within the groupings and small sample size.

The principal failure mode (excessive offset voltage and saturation of the amplifier) can be attributed to surface effects for the following reasons:

(1) Circuit temperature remained essentially unchanged throughout the exposures. The temperature of the pulsed (unbiased) group and ambient temperature tracked excellently between 69 and 74 F. Dynamic and static groups (with bias applied) also tracked together between 79 and 85 F.

(2) The unbiased circuits (pulsed) did not exhibit any of the adverse effects observed in the biased (static and dynamic) circuits. This behavior is typical of surface effects.

(3) Saturation effects were not permanent, as are bulk damage effects, since they appeared to heal themselves. Note that the postcharacterization measurements are not significantly different from the pre-irradiation measurements.

(4) The total electron fluence, 7.6×10^{12} e/cm^2 , should not be sufficient to cause extensive bulk damage in advanced silicon transistors.

(5) The circuit makes use of transistors operating at very low power. For example, the transistor (Q_{11} of the figure used in Test Result Summaries) employed as a current source in the input section of the amplifier has an average collector current of only 20 microamperes. Transistors operating in low current

modes have been known to show current gain degradation due to surface channeling effects.(7) (8)

Although the evidence strongly indicates surface effects the possibility can not be overlooked that exposure rate is a significant factor.

An attempt to conclusively isolate the problem area to a single transistor is not feasible. There are clues, however, which point to the input circuitry. First of all, both output transistors are operating normally as evidenced by the stability of the plus and minus saturation levels. The fact that saturation levels remained stable indicates that gain has not degraded and that base drive is adequate. Second, the output stage incorporates feedback so that d-c shifts in the bias levels of transistors (Q_9, Q_{12}, Q_{13}, and Q_{14}) within the feedback loop should be minimized. Third, the sheer magnitude of the effect and the rapidity of recovery in the initial minute following an exposure precludes the possibility that it was caused by a single transistor near the output. The observed saturation could more easily be explained by an internal circuit inbalance of somewhat more than 200 mv (referred to the input) which was then amplified.

Signetics SE505G

Signetics SE505G is a general-purpose differential amplifier fabricated by planar epitaxial techniques. The single-ended open loop

(7) Stanley, A., "Space Radiation Effects on High Gain Low Current Silicon Planar Transistors", Lincoln Laboratory, under Contract Number AF 19 (628) - 5167 (February 9, 1965, revised October 25, 1965)

(8) Nelson, D.L., and Sweet, R. J., "Mechanisms of Ionizing Radiation Surface Effects on Transistors", Paper at the IEEE Annual Conference on Nuclear and Space Radiation Effects, Palo Alto, California (July 18-22, 1966), under Contract NAS-8-20135.

differential voltage gain is specified nominally as 1800. First failure occurred at a fluence of 6 x 10^{13} e/cm^2, where one unit showed greater than 5 percent reduction in closed-loop gain, corresponding to 60 percent reduction in open loop gain.

Input bias current[(9)] increased significantly in all exposed groups compared to the control group. The percent average increases ranged from 109 percent in the static group to 132 percent for the pulsed group.

The statistics also indicate that damage to the pulsed group was significantly greater than in the static group. Nevertheless, the increased input bias current lowers the amplifier input impedance which in effect increases the loading on the stage previous to the amplifier.

Amplifier offset voltage measured in the pre/postirradiation characterizations increased from 130 to 240 percent. However, most of this change may be attributed to the change in input bias current, since the measuring circuit incorporated unbalanced input impedance. The impedance to ground at one input was 120 ohms, and at the other less than 1 ohm. Thus, the change in input bias current (per input) multiplied by 120 ohms (the external resistance which unbalanced the inputs) gives a change in offset voltage which can not be assigned to the amplifier. Subtracting this change induced by the external circuitry from the measured value indicated that the true change in amplifier offset voltage was approximately 13 to 56 percent greater than initial. No significant differences were noted between the groups.

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(9) Input bias current, as it is used here, is the sum of currents from both inputs to ground, and hence is twice the value normally specified by the manufacturer.

The voltage measured during the exposure for pulsed and static circuits is also labeled V offset, but is not the same parameter. This variable was defined in the same manner as an operational amplifier. It is a single-ended measurement (not differential) and must not be confused with the figure given in the specification sheet or the pre/post characterization V offset discussed above. The single-ended offset voltage increased from 26 to 60 percent for the static group, but only 7.6 percent for the pulsed group. Here a significant difference between groups is evident as a result of bias conditions. The pulsed group with no voltage applied would not enhance charge migration or charge build-up (surface problems) which could cause increased leakage currents and increased offset voltage. As a consequence, this result would indicate a possible surface effects problem.

Amplifier gain decreased significantly in all exposed groups. Postirradiation characterization measurements showed reductions of between 26 and 30 percent open- loop gain, but no significant differences between exposed groups. Gain degradation was also evident in these groups while the exposure was in progress. Closed-loop gain (gain about 100) degraded by roughly 5 percent in the static group, 9 percent in the dynamic group, and 17 percent in the pulsed group. Some recovery was noted 1 week later in the static and pulsed groups. (Post 1-week measurements for the dynamic group were not calibrated properly, and hence no comparison of annealing can be made.)

The balanced output, d-c voltage showed a significant reduction of between 3.2 and 10.5 percent. No statistically significant intergroup differences are evident.

Saturation voltages, i.e., the maximum positive and negative output voltages of the amplifier, did not change significantly as indicated by pre/postirradiation characterization. However, the measurements taken during the exposure show drifting toward positive values, and one failure was noted at 1.5×10^{14} e/cm^2. This device (Unit 8) failed because the negative saturation voltage decreased in magnitude to less than -1.6 volts specified as minimum. The positive output limit also decreased, and later all five statically operated units failed. Both the positive and negative saturation voltage of the pulsed circuits remained unchanged from the initial to final in-site measurements.

Although resistance appears to increase when comparing exposed groups to the control group, there is no statistically significant change.

Amplifier bandwidth increased substantially 40 to 45 percent in all exposed groups, indicating that the minority-carrier lifetime had been reduced. This type of behavior is characteristic of bulk damage effects.

No significant changes occurred in the amplifier input common mode rejection ratio or percent distortion in the output.

Amelco A13 251

Amelco's A13 251 is a planar diffused operational amplifier with a nominal open loop gain of 20,000. First failure occurred at an electron fluence less than 10^{12} e/cm^2, and was due to a decrease in closed-loop gain (initially $\sim$150) greater than 5 percent, corresponding to a reduction in open-loop gain of approximately 91 percent. The principal effects on operation during the exposure were drifting output voltage (with excursions in both positive and negative directions) and decreasing circuit gain. Because the circuits appeared to be operating normally - except for a reduction in gain - the exposures were continued until a total fluence of 3.7×10^{14} e/cm^2 was attained. Statistically significant changes in the amplifier parameters measured following the irradiation were noted in input offset voltage, resistance, transistor current gain, amplifier gain, and bandwidth. No statistically significant differences were found in amplifier saturation voltage, input bias current, or common mode rejection ratio. A significant increase in offset voltage of all exposed groups compared to the control group is indicated by the statistics. Post-radiation in-site measurements showed that the pulsed circuits had experienced an average increase in offset voltage of only 1.5 mv (initial value 7.4 mv), whereas the statically operated circuits experienced an increase of 88. mv (initial value 6.2 mv). Clearly there is a significant difference in effects between the pulsed and statically operated circuits. Damage which is bias dependent, as this seems to be, can often be correlated with surface effects. Pre- and post-characterization offset voltages were measured by a different circuit than used for in-site measurements in order to minimize the number of leads brought out from the sample to the measuring equipment. Values of offset voltage differ slightly(10) from one circuit configuration to the other because of differences in

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(10) Sign of pre/post characterization offset voltage is opposite that of in-site data because the former were referred to the inverting input.

circuit input impedance, but the trend is the same. It is interesting to note that offset voltages measured at 5-weeks post exposure were almost the same for static (9.4 mv), pulsed (6.5 mv), and dynamic (8.8 mv) circuits. Yet very little annealing was noticed in the 1-week post radiation measurements on the static group. It is possible that the circuit operating time preceding the post characterization offset voltage measurements was sufficient to cause the greater part of this annealing. Some support is given to the argument by the following discussion of the changes in gain. However, sufficient information to validate or refute this hypothesis was not obtained.

A statistically significant decrease in gain was observed for all irradiated groups compared to the control group. The static group, operating with an initial closed-loop gain of 150 decreased to a final gain of 42, implying that open-loop amplifier gain was probably not greater than 60. Open-loop gain degradation was also calculated for the dynamic group. Compared to the initial values, open loop gain was about 12 percent after 1×10^{14} e/cm^2 and 10 percent for 3.7×10^{14} e/cm^2. These low open-loop gains correspond to a reduction of roughly 4 percent in the closed-loop gain. Average pulsed circuit gain was measured as 101.5 (closedloop) initially and 103.7 as a final value. Obviously, the closed-loop gain of these operational amplifiers could not have increased above the initial value unless the input impedance had degraded severely. This increase is roughly equal to the experimental error. Average closed-loop gain 1-week post radiation was measured as 96.2. This decrease is a real change, but, because the experimental uncertainty is about one-half of this change, it is not possible to meaningfully compare operation of the pulsed and dynamic circuits. However, the relatively large change in the static circuit compared to that of the pulsed circuits is easily recognized as a significant difference. It is remarkable that post characterization measurements taken 5 weeks following the radiation showed no real differences between irradiated groups. Static, dynamic, and pulsed circuits exhibited open-loop gains degraded between 33 and 40 percent. The statically operated circuits appear to have recovered from their very low gain condition. An increase in bandwidth was evident in all three irradiated groups. The statistics show a strong difference between the pulsed group and the control group, and somewhat smaller differences when comparing the static and dynamic groups to the control group. The increase in amplifier bandwidth is consistent with decreased minority carrier lifetime which one associates with bulk damage. Figure 10c, which shows pulsed amplifier response immediately before and after irradiation, also illustrates this effect by way of an improvement in rise time. All of the exposed groups experienced increases in bandwidth of from 1.8 to 3.0 times the initial values.

Significant changes occurred in the gain of both NPN and PNP-type transistors of all irradiated groups. The NPN transistors experienced gain reductions of between 49 and 52 percent, depending upon the group. No significant differences exist between irradiated groups. All irradiated PNP transistors, regardless of grouping, degraded from an initial gain of 8 or 9 to a final gain of somewhere between 0.2 and 0.6. This result was expected since these devices are lateral PNP structures with wide base widths, and hence less radiation resistant to bulk damage. The circuit function of these PNP transistors is noncritical, and thus even a 50 percent reduction in gain should not greatly affect amplifier performance. The fact that both PNP and NPN transistors degraded similarly regardless of bias grouping is strong evidence that the damage was in fact due to bulk damage.

The saturation voltage (V_{SAT}), as it is used here, is defined as the difference between the supply voltage ($\pm$ 12 volts) and the saturation voltage of the pertinent output transistor. That is, (-) V_{SAT} represents the maximum negative voltage capability of the output, and (+) V_{SAT} is the corresponding positive limit. The pre- and postirradiation characterization measurements of V_{SAT} were the same, at least as nearly as could be determined with an oscilloscope. Measurements made with the chart recorder, which has better resolution, show definite reductions in V_{SAT} during the exposure. Circuits operating in the static mode showed reductions of between 5 and 18 percent in (+) V_{SAT} and 7 to 13 percent reductions in (-) V_{SAT}. Pulsed circuits operated in the static mode experienced smaller reductions in (+) V_{SAT}, only 2.7 to 4.5 percent. No conclusions can be drawn from the data of (+) V_{SAT} (which shows increasing (+) V_{SAT}) measured under pulsed conditions, since the pulse width was insufficient to allow circuit stabilization. It should also be noted that the static group was operated with 1 K-ohm loads, whereas the pulsed group was not. This is the reason for greater V_{SAT} values of the pulsed group.

Although the statistics do not indicate a significant difference in input bias current[(11)], it should be obvious that the general trend is toward greater currents. With the exception of a very large increase

(11) This current represents the sum of currents flowing from inverting and noninverting inputs to ground, and hence is twice the current normally specified by the manufacturer as "input bias current".

in one unit (#13) of the pulsed group, all exposed units increased from an initial value of about 0.5 μA to 2.5 μA. This represents an increase in leakage current of the input transistors and results in reduced amplifier input impedance.

The resistance of a substrate resistor, nominally 20 K-ohms, was monitored in order to determine whether significant changes in bulk resistivity had occurred. Increases in resistance varied considerably from device to device, but no outstanding differences were noted between groups. Average changes ranged from 5 to 9 percent above initial. The measured resistor was the only substrate resistor in the amplifier and performed a noncritical circuit function. Because it was a substrate resistor, the changes which occurred were probably greater than changes in the diffused resistors, due to the higher resistivity material employed in the former type. No meaningful changes or trends were noted in amplifier common mode rejection ratio.

Analysis of Test Data for Micropower Circuits

Philco PL987

Philco's PL987 is a micropower MEL (Micro Energy Logic) NAND gate fabricated using silicon planar technology. A typical gate has a propagation delay of less than 100 nanoseconds at an average power dissipation of 440 microwatts. The first failure was recorded after an electron fluence of 1.45 x 10^{15} e/cm^2, at which point the irradiation was terminated. At this point the low-level voltage (V_{zero}) of one device had exceeded the manufacturer's specified limit of 0.215 volts. The average static circuit output low level had increased by about 14 percent. The multi-stage propagation delay for the dynamic circuits had increased by 32 percent. During the 1-week interim between the irradiation and the monitored parameter retest the parameter values generally showed only slight recovery. The pulsed circuits operating in the static mode, however, showed an average increase of 19 percent in V_{zero} which continued to increase to 35 percent by the post radiation 1-week measurement.

The degradation in electric parameters can be attributed principally to decrease in gain of the output transistor. The decrease in gain as exemplified by the large decreases in output drive current capability (-36 to -43 percent) is not necessarily reflected in the changes in storage time (-2.5 to -4.5 percent). This would indicate that the gain change is not critically dependent on minority-carrier lifetime changes in the base region, but on surface recombination velocity and emitter efficiency. The low operating currents of the transistors accentuate the importance of these latter effects. The irradiated circuits are still operable at room temperature. Primary design difficulties will result from increased low-level output voltage at the low temperature extremes. The radiation failure level can be extended by reducing the permissible fan-out. This step will provide a greater drive current to each of the remaining load circuits, and consequently lower their V_{zero} output characteristics.

The input parameters, input drive current, input leakage current, and input voltage levels show no changes of engineering significance. However, the input leakage current does show an interesting statistically significant decrease. The cause of such a change is not presently explainable, but was also observed in the T^2L gate and flip-flop circuits of last year's program.

The pull-up resistors increased slightly greater than 1 percent. The rise, fall, and delay times show significant increases of roughly 40, 75, and 25 percent, respectively. The storage time shows small changes which do not appear to be statistically significant. Changes in these transient parameters are consistent with general transistor gain and V_{BEon} degradation, and would account for the changes in multistage propagation delay. Generally no statistically significant differences appeared among the test groups.

Westinghouse WS113Q

Westinghouse's WS113Q is a micropower complementary flip-flop fabricated using a planar epitaxial process. A typical flip-flop has a counting rate of 1 megahertz and an average power dissipation of 500 microwatts if operated at a supply voltage of 3 volts. The tested devices were taken from a research production run and as a result are not likely to be representative of later devices.

The first failure, a decrease in the high level output voltage to below 2.50 volts, occurred at 8.0×10^{14} e/cm^2. The irradiation was continued to a total exposure of 9.4×10^{14} e/cm^2. At this point the average static low level output voltage had increased by 118 percent to 0.142 volt while the average static high-level output voltage had decreased only 5 percent to 2.73 volts. The pulsed circuits showed an increase of 177 percent in low-level output for the static operating mode. This increased by the post radiation 1-week measurements to 215 percent. Still the average low level voltage was only 0.183 volt. It should be noted that a direct reset pulse had to be applied continuously to the static circuits to keep the circuits in the proper state.

The degradation occurring in this device type is principally due to decrease in transistor gain. The clocked input threshold voltage showed a significant decrease of 13, 38, and 23 percent for the pulsed, dynamic, and static circuits respectively. These changes are consistent with the slight decrease in clocked input current resulting from increased forward diode voltage and decreased transistor gain. The clocked output voltage levels showed significant changes. The low-level output increased and the high-level output decreased. This would be expected since these levels are determined by the saturation voltages of the complimentary transistors. The direct-set transistor saturation voltage showed, as expected, statistically significant increases of 519, 693, and 708 percent for the pulsed, dynamic and static devices, respectively. Changes in the power supply current, clocked input leakage and drive currents, direct set-reset threshold voltage, direct set-reset input drive current, and minimum voltage amplitude to trigger were sufficiently small as to not be of engineering significance. The transient parameters showed no statistically significant changes. The general trend for these parameters is for the rise, fall, and delay times to increase and storage time to decrease.

For the direct set-reset transistor saturation voltage, the input threshold voltages and the output zero voltage with full load there appears to be significantly less degradation in the pulse circuit group than in the dynamic or static groups.

It is interesting to note that the low-level output voltage even with its 118 percent increase had only reached a voltage of 0.142 volt. The failure limit for low-level output voltage is 0.500, well above the value obtained. It is difficult to predict how much more radiation the NPN transistors could absorb before the 0.500 level is exceeded.

The period of operation in a radiation environment may be changed by the type of loading placed on the output of the circuit. WS113Q can be loaded both to ground and to V_{cc}. This device was loaded to V_{cc} during irradiation and yet the high-level output decreased to the failure limit. Since the high-level voltage in this case is the saturation voltage of a PNP transistor, it is very likely that the device may have failed earlier if it were loaded to ground.

Analysis of Test Data for MOS Digital Circuits

General Instrument 7532

The 7532 is a dual NOR gate which is constructed on a single monolithic silicon chip utilizing MOS technology. These devices were exposed to 1.5 Mev electrons. The lower energy electrons should be more destructive to surface conditions and hence be more deleterious to circuit operation.

The first failure occured quickly at a fluence of less than 2.5×10^{12} e/cm^2. The exposure was continued to a total fluence of 5×10^{12} e/cm^2. At this time the average static low-level output had increased by 113 percent while the average static high-level voltage had decreased by 24 percent. Both voltage levels exceeded their specifications of -4 volts and -9 volts at approximately the same time. The ring oscillator failed before the static circuits at 1.2×10^{12} e/cm^2. The oscillator, once exposed, was not operable until the post radiation plus 1-week measurements when the supplemental load resistors were removed from the individual devices. At that time the multistage propogation delay had increased by 4,150 percent. The worst-case load, 47 K-ohms to ground, was applied to the oscillator circuits during irradiation. This load may seem severe. It is, however, the same load that is specified for worst-case fan-out of 7 for General Instrument's 7531 (MEM 529). To provide contrast between loaded and unloaded units, it was decided that the load card for the static units would not be used. The difference in failure rates due to this change in procedure was partially masked by the short time to failure ($<$ 25 seconds), but is indicated by the first failure points of the dynamic and static circuits. The pulse circuits showed only small (2 - 10 percent) average changes in the V_{one} output level.

The changes which occurred during the exposure can basically be attributed to increases in gate threshold voltages ranging from 7 to 47 percent. The d-c transconductance decreased in all cases. It may appear, however, as though there is an increase for the pulsed group, but this is caused by one sample number 13. The reason for this odd change is not known. Although the d-c transconductance may appear in this case to be a significantly large decrease, it may in reality not be so large. The reason for this is that the transconductance was measured at constant gate- and drain- to source voltages, corresponding to different values of drain currents in the before and after measurements. It is known that shifts in drain current may directly change the transconductance. The drain-to-source current also showed significant decreases which can be attributed directly to increases in gate threshold voltage.

The change in high-level output voltages were about 4.5, -43, and -32 percent for the pulsed, dynamic, and static groups, respectively. The decreases in V_{one} might best be explained by increases in drain to source leakage currents. Other data(6) have indicated that leakage currents can increase by four to five orders of magnitude after an exposure of 5.00×10^5 rads or approximately $8 \times 10^{12} e/cm^2$. Such current increases could cause decreases of the magnitude observed. Significant increases were noted for the input voltage levels. V_{zero} with the output unloaded showed changes of 47, -3, 17, and -3.5 percent while the V_{one} with the output unloaded showed changes of 25, 7, 9, and -0.5 percent for the pulsed, dynamic, static, and control units, respectively. However, when the devices were loaded to ground, the V_{one} level showed increases of 29, 20, and 30 percent for pulsed, dynamic, and static groups, respectively. The low level, however, would not operate for the dynamic and static circuits. The pulsed

(6) Gordon, F., Jr., and Wannamaker, H. E., Jr., "The Effects of Space Radiation on MOSFET Devices and Some Application Implications of Those Effects", Paper at IEEE Annual Conference on Nuclear and Space Radiation Effects, Palo Alto, Californis (July 18-22, 1966)

circuits showed a 27 percent increase in low-level voltage. These changes would be expected since this is essentially an increase in gate threshold voltage.

The low-level output voltages showed inconsistent results for the dynamic and static groups. For gate 3(A) the gate threshold appears to increase, but for gate 4(B) the gate threshold appears to decrease. The only known difference between these two gates is that gate 3 was used for circuit operation during irradiation Ghile gate 4 was grounded. The reason for the decrease is not apparent at this time.

The rise, fall, delay, and storage times showed significant increases. The storage time had changes of 6.7, 90, and 80 percent. The fall time had changes of 15, 207, and 175 percent. The delay time showed changes of 38, 175, and 131 percent and the rise time showed changes of 111, 201, and 228 percent. For MOS transistor inverters, the switching times depend not only on device parameters, but also on the circuit parameters. Wallmark and Johnson's book Field Effect transistors: Physics, Technology and Applications indicates that, although no straightforward dependence can be cited for the "turn on" of a resistor-loaded inverter, "turn-off" time is clearly proportional to $R_L C_O$ time constant. R_L is the load resistance while C_O is the output capacitance including that of the driven load. Since in this case a portion of the load is an MOS transistor biased to serve as a load resistor, we could expect changes to occur in the transient parameters as changes occur in the load device.

Significant differences were noted between the biased and unbiased samples. The unbiased samples showed less degradation than did the biased samples except for the input voltage levels which showed more change for the pulse units. Generally there was not a significant difference between the two biased groupings. The differences between the biased and unbiased sample might be expected if one considers that the damage is due to surface damage or channeling which is highly influenced by electric fields.

Some improvement in device operation in a radiation environment might be achieved by changing the bias levels on the biasing transistor. To what extent this will affect the useful operation of the device is not known. It will not, most likely, extend the operation by more than an order of magnitude of electron fluence.

It should be noted that, due to the type of failure occurring (decrease in high level output), decreases in fan-out requirements may or may not change the period of operation for this device type in a radiation environment. The change depends upon which output level causes the device failure. Failure of the high level may be effected by changes in load depending upon magnitude of the loads and the apparent magnitude of the drain-to-source resistance of the transistor used as a pull-up resistor.

General Instrument 7531(MEM529)

The 7531 is an RST MOS Flip-Flop which is constructed on a single monolithic silicon chip utilizing MOS technology. These devices were exposed to 1.5 Mev electrons.

The first failure was almost immediate, occurring at a fluence of less than 1.2×10^{11} e/cm^2 or in less than 12 seconds of exposure time. The irradiation was continued to a fluence of 1×10^{12} e/cm^2. The failure mode for the static circuits was a change in the high-level output voltage to a value which was less negative than -10 volts. The low-level output voltage remained at less than -0.1 volt. The dynamic circuits failed almost immediately and later also were not holding state. As a result no dynamic measurement could be made. The pulsed circuits showed slightly smaller changes than the static circuits and showed essentially no recovery.

It should be noted in looking at the data that many of the devices appear to have degraded enough to be inoperable in the clocked mode. The information obtained from the tests on VTH-3 and VTH-6 is not sufficient to offer any explanation to this problem.

The other input voltage threshold measurement on the direct set-reset inputs indicates a definite decrease in gate threshold voltage. This is not inconsistent with what has been observed in single MOS transistors since this change is caused by the specific circuit characteristics. Assuming the expected to happen, that is, the gate threshold voltage to increase, then it follows that the cross-coupled transistors would turn "off" with less voltage change. The direct set-reset transistors would not have to be turned on as hard to get this smaller voltage change, resulting in an apparent decrease in gate threshold voltage. Another factor which could aid slightly the decrease in the voltage required to change the cross-coupled transistor would be an increase in leakage current. Increased leakage currents would reduce to maximum drain-to-source voltage for these transistors.

The limited number of devices on which transient parameters could be measured indicated increases in the rise, fall, delay, and store times. This would be generally expected as mentioned in the analysis of the 7532.

The V_{one} output voltage levels loaded showed changes of -2, -59, and -55 percent for pulsed, dynamic, and static circuits and the unloaded outputs showed slightly smaller percentage changes. This decrease can be explained as for the 7532 by increased leakage currents.

The changes in minimum clock pulse width and amplitude showed no significant changes.

Significant differences in groups were noted for most parameters. The pulsed group changes less than either the static or dynamic groups, but there was never a significant difference between the static and dynamic groups.

Fairchild μM400 (now called μM-3400)

The μM400 is five monolithic MOSFET devices sharing a common drain. These transistors are p-channel enhancement devices made by the diffused silicon planar II process. The devices were irradiated with 1.5 Mev electrons. For operation in the electron environment, the devices had their source terminals tied together and to ground and the drain terminal tied to -12 volts through a 10-K resistor. In this way one package (five transistors) functioned as a five-input NOR gate. The test conditions may not have been best for maximum efficiency.

The first failure for these devices operating in a static gate configuration was recorded at less than 1.2×10^{11} e/cm^2 or less than 12 seconds of machine time. This almost immediate failure would indicate a possible rate effect due to the flux of 10^{10} e/cm^2-sec. A lower flux, more similar to that in space, might result in less significant degradation for the same fluence. The exposure was continued to a total fluence of 2.5 x 10^{11} e/cm^2. It should be mentioned that the failure limits for this device of -4 volts for V_{zero} and -10 volts for V_{one} were arbitrary and set by Battelle. The failure limits were made to be comparable to those of the other MOS circuits for ease of analysis. The gates operating in the static configuration showed average changes in V_{zero} and V_{one} of 205 percent and -1 percent, respectively. The pulsed circuits operating in the static mode showed 48 percent increase in V_{zero}. While operating in the pulsed mode they showed a 70 percent increase in V_{zero}. The ring oscillator functioned only a short time. By 4 x 10^{10} e/cm^2 the amplitude of oscillation had decreased 55 percent and operation ceased shortly thereafter. At 4 x 10^{10} e/cm^2 the multistage propagation delay had not changed.

The changes which occurred appear for the most part to be the direct result of increased gate threshold voltage. The gate threshold voltage showed changes of 15, 55, and 39 percent for pulsed, dynamic, and static circuits. The "on" drain current decreased 30, 54, and 50 percent while the transconductance decreased 12, 39, and 22 percent for the pulsed, dynamic, and static circuits. The dynamic drain resistance generally increased. The drain-leakage current appears to have increased, but not enough to cause the decrease in V_{one} output voltage observed at post-radiation-plus-1-week measurements. A partial reason would be that the measurement was made at -10 volts instead of the -12 volts used for gate operation. The breakdown voltages, the gate to source, gate to drain, and gate to body capacitances, and gate leakage current showed no significant changes. The nonsignificant changes in the capacitance measurements were a little surprising since it was expected that surface-charge changes would appears as a change in these capacitances.

Analysis of Data for Dielectrically Isolated Circuits

Radiation Incorporated RD210

The RD210 is a dielectrically isolated DTL NAND/NOR gate. This is an ultrahigh speed gate with a typical propagation delay of 7 nanoseconds which is fabricated using passivated epitaxial techniques. Typical power dissipation is 10 milliwatts.

The first failure, V_{zero} exceeding 0.400 volts, was recorded after an electron fluence of 4.15×10^{14} e/cm^2. The irradiation was terminated shortly thereafter at 4.6×10^{14} e/cm^2. At that point the average value of the static low-level output had increased by 29 percent.

The observed degradation in parameters can be attributed principally to decrease in transistor gain. The changes of engineering significance were the decreases in gain and output drive current and increases in output saturation voltage and rise time. Other parameters which had statistically significant parameter changes due to radiation, but which were not large enough to be of engineering significance were the decreases in input drive current and input voltage threshold levels.

The remaining parameters, input leakage, input bias resistance, fall, delay, storage times, and diode forward voltage showed no statistically significant changes due to the electron exposure. At first glance there appears to be an inconsistency with the results that the input bias current and input threshold voltage show a significant decrease and the input bias resistance and diode forward voltage show no significant change. The order of magnitude of the change in input bias current and threshold voltage are such that small flucuations of the bias resistance and diode forward voltage could cause the change and yet not be recognized as a change due to measurement errors of these quantities. As with the PL987 circuit, changes in storage time, output saturation voltage, and output drive current indicate that possibly the transistor gain has decreased by means other than decrease in bulk minority-carrier lifetime.

There are several indications that this device type could be operated to a higher fluence. First, these devices were early production devices and had slightly higher than normal output saturation voltages. That is, the specified typical value for V_{zero} is 0.250 volts while the average for these circuits was 0.315. Second, a reduction in fan-out requirements would lower the necessary output current drive and hence lower output saturation voltage. And third it appears as though the circuit could function at a specified maximum low level of 0.450 volts instead of the specified 0.400 volt. Because these circuits were early production items they were tested to tentative specifications which are not necessarily applicable at the present time.

Motorola Triple 3-input DTL gate

The sample of 20 DTL gates was broken down evenly into two groups, the DTL-EPIC gates and the MC962 gates. The DTL-EPIC devices are a dielectric isolated circuit while the MC962 devices are a monolithic circuit. Both circuits are electrically a triple 3-input NAND gate using the same DTL configuration.

In reviewing the initial means of the two sets of devices, several differences are apparent. The pull-up resistor for the dielectric isolation has a slightly higher resistance value than the monolithic circuit. The output drive current, the rise time and the storage time are larger for EPIC circuits than the MC962 indicating that the output transistor is slightly different in basic properties.

The first failure for these DTL gates occurred at 3.88 x 10^{15} e/cm^2. This failure was a MC962 device whose low level exceeded 0.40 volt. It should be noted that the one EPIC device number 4 operated in the static mode showed only a very little increase. By the end of the exposure, 3.94 x 10^{15} e/cm^2, the low-level output of the EPIC device had only increased to about 0.1000 volt. All the pulsed devices were dielectrically isolated and had an average zero level of 0.383 at the maximum fluence. This average was raised a great deal by one device in this group whose value was 0.970 volts while the others were 0.335, 0.239, 0.220, and 0.192. From past experience one would generally expect the pulsed circuits to show slightly more degradation than the biased samples.

The devices operating in the dynamic group showed decreases in the multistage propagation delay of 87 percent. There were 3 MC962's and 2 EPIC devices in the oscillator. Indications from the summarized transient parameter data for the two groups are that changes in these parameters are roughly the same. Neither device type can be said to have caused a majority of the change.

The changes in input voltage levels, input drive current, and input leakage current for both groups appear to be about the same, but are not generally large enough to be of engineering significance. The changes in the pull-up resistor, while not being of engineering significance, are larger for the MC962 devices. The reason being that the MC962 resistors are diffused while the EPIC resistors are thin film. The output drive current showed significant decreases on the order of 75 percent for both device types. This decrease would be expected with gain degradation of the output transistors.

The transient parameters show no significant changes, but indicate, in general, the expected trend with rise, fall, and delay times increasing and storage time decreasing for both devices.

It appears that for this particular type of DTL gate the dielectrically isolated circuit is more radiation resistant than the monolithic circuit. However, due to the indications in initial characterization of differences in intrinsic circuit design and the lack of several samples in each condition during irradiation, the only statement that can be made in comparing the MC962 and EPIC devices is that there are no differences in circuit response which can be directly attributed to dielectric isolation.

It is interesting to note how closely the changes in this circuit follow changes in last year's circuit A-5, which is the same circuit configuration but in monolithic form. It is expected that first failure fluences would be about the same if the specified limits and loading were the same.

RESULTS

In this section the effects of the radiation exposure on each of the 17 microcircuit types are tabulated in Test Result Summary Sheets. These sheets are intended to give a concise picture of the radiation-induced effects as determined from the in situ and characterization measurements. Comprehensive data may be found in Appendix III.

The computer program used for summarizing and tabulating the raw data is presented in Appendix IV.

A discussion of the summarized data format has been presented at the beginning of the previous section "Analysis of Data".

Symbols

The following symbols are used in the data result summaries:

BAL OUT DC - Balanced d-c output level

BVDSS - Drain source voltage breakdown

BVSDS - Source-drain voltage breakdown

BW - Bandwidth

CGB-2 - Gate body capacity for transistor 2

CGD-2 - Gate drain capacity for transistor 2

CGS-2 - Gate source capacity for transistor 2

CMRR - Common mode rejection ratio

DISTORTION - Percent distortion in output

GAIN - Circuit gain

GM - D-C Transconductance

HFE NPN - Gain of NPN output transistor

HFE PNP - Gain of PNP output transistor

IDSS-2 - Drain leakage current for transistor 2

IIN BIAS - Input bias current

IIN DRIVE - Input drive current

IIN LEAK - Input leakage current

IIN LEAK-G-2 Gate leakage current for transistor 2

IOUT DRIVE - Output drive current capability

IPOWER - Power supply current

ISDS-2 "On" drain current for transistor 2

R12 or R110 - Resistance between pins 1 and 2 or pins 1 and 10

RDS - Dynamic drain resistance

RIN - Input Resistance

RPULL-UP - Pull-up resistance

T-RISE
T-FALL
T-DELAY
T-STORE
Transient parameters

TW - Minimum clock pulse width required for operation

VA - Minimum clock pulse amplitude required for operation

VFORWARD - Input diode forward voltage

VMX ZERO-1
VMIN ONE-1
VMX ZERO-8
VMIN ONE-8
Input voltage levels for a fan out of 1 and 8

V OFFSET - Offset voltage

VOUT 1-4
VOUT 1-7
Output one voltage for pins 4 and 7

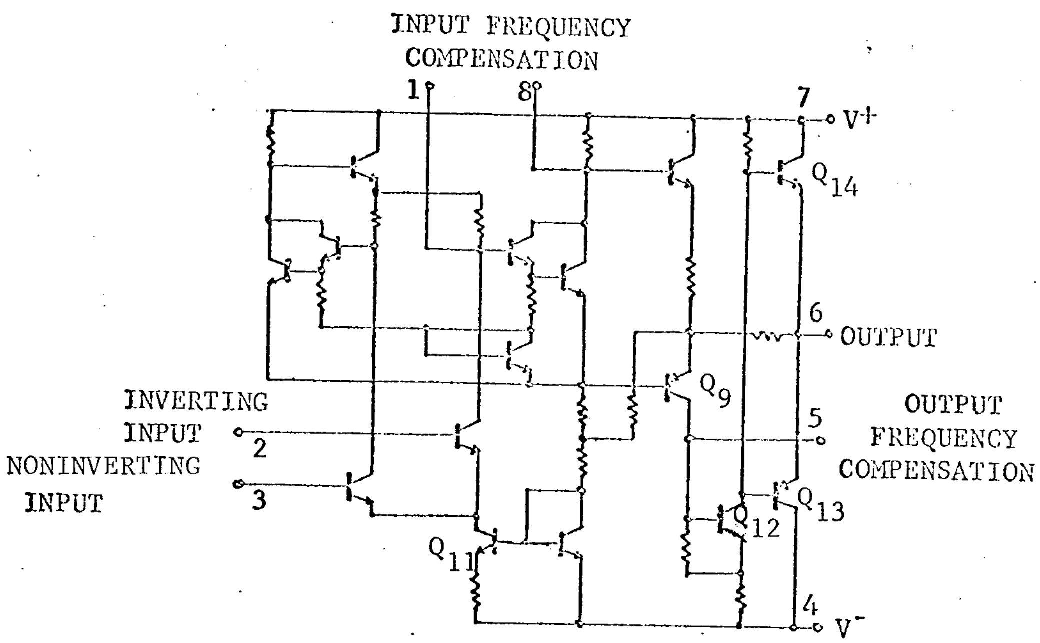
VOUT 0-4
VOUT 0-7
Output zero voltage for pins 4 and 7

VSAT VSAT 2+ VSAT 10-	Output saturation with indications of pin and direction of saturation
VTH-2 VTH-4	Gate threshold voltage for gates 2 and 4
VTHC-3 VTHC-8	Clocked set-reset input threshold voltage at pins 3 and 8

TEST RESULT SUMMARY SHEET

Circuit Identification Code: Fairchild μA709

Circuit Diagram:



Circuit Description:

Function: Operational Amplifier
Process: Planar Epitaxial
Gain: 32,000 Typical

TEST RESULT SUMMARY SHEET (Continued)

Code UA709

IN SITE DATA

Electron Fluence:
  To First Failure $< 7 \times 10^{11}$ e/cm^2
  Test Total 7.6×10^{12} e/cm^2

Failure Mode: V_{offset} exceeded 5×10^{-3} Volts

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature			84 F	
Gain	Mean Value	100.2	----	101.5	94.0
	Percent Change in Mean Value	----	----	1.3	- 6.2
	Spread min./max.	97.5/102.5	----	98.7/103.7	92.5/95.0
V_{offset}	Mean Value (Volts x 10^{-3})	1.5	----	26.9	7.0
	Percent Change in Mean Value	----	----	169.3	366.6
	Spread min./max.	1.0/2.0	----	6.6/48.7	2.1/12.3
Pulsed Circuits	Temperature			72 F	
Gain Static Mode	Mean Value	102.2	----	103.0	97.2*
	Percent Change in Mean Value	----	----	0.8%	-4.9%
	Spread min./max.	97.5/106.0	----	100.0/105.0	95.0/98.7
V_{offset} Static Mode Absolute Value	Mean Value (Volts x 10^{-3})	1.4	----	1.7	2.3*
	Percent Change in Mean Value	----	----	21.4	64.2
	Spread min./max. (Volts x 10^{-3})	-1.4/2.4	----	-2.8/2.4	-2.0/4.0
Dynamic Circuits	Temperature			85 F	
Relative Gain (Open Loop)	Percent Change from Initial Value	----	----	No change	----

*After 15 minutes continuous operation.

TEST RESULT SUMMARY SHEET (Continued)

Code μA709

IN SITE DATA

Electron Fluence:
To First Failure $< 7 \times 10^{11}$ e/cm^2
Test Total 7.6×10^{12} e/cm^2

Failure Mode: V_{offset} exceeded 5×10^{-3} Volts

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature			84 F	
Positive V_{SAT}	Mean Value (Volts)	9.7	----	8.7*	10.3
	Percent Change in Mean Value (%)	----	----	-10.3	+6.2
	Spread min./max.	9.4/10.8	----	8.6/9.0	10.3/10.3
Negative V_{SAT}	Mean Value (Volts)	10.4	----	10.2*	9.8
	Percent Change in Mean Value	----	----	1.9	5.8
	Spread min./max.	10.3/10.5	----	10.2/10.5	9.7/9.9
Pulsed Circuits	Temperature			72 F	
Positive V_{SAT} Static Mode	Mean Value (Volts)	11.1	----	11.0	10.3
	Percent Change in Mean Value (%)	----	----	0.9	7.2
	Spread min./max.	11.0/11.1	----	10.9/11.0	10.3/10.3
Negative V_{SAT} Static Mode	Mean Value (Volts)	10.8	----	10.8	10.3
	Percent Change in Mean Value (%)	----	----	0	4.6
	Spread min./max.	10.8/10.9	----	10.8/10.9	10.3/10.3
Dynamic Circuits	Temperature				

*Only 3 Devices considered, 2 Devices indicated negative saturation for all input levels.

CODE μA709

	GAIN	VSAT+	VSAT-	
UNITS	X10**3	VOLTS	VOLTS	
GROUP P				
NUMBER	5	5	5	
INITIAL MEAN	2.784+001	1.122+001	1.110+001	
AVERAGE CHANGE	-1.500+000	2.400-001	-1.000-001	
STD OF MEAN	1.414+000	1.275-001	0.000+000	
AVE PER CENT CHANGE	-5.349+000	2.141+000	-9.009-001	
INTERVAL ESTIMATE	-1.103+001	8.775-001	-9.009-001	
AS PER CENT	2.527-001	3.401+000	-9.009-001	
PER CENT AVE CHANGE	-5.388+000	2.139+000	-9.009-001	
GROUP D				
NUMBER	5	5	5	
INITIAL MEAN	2.754+001	1.132+001	1.104+001	
AVERAGE CHANGE	-3.680+000	1.400-001	0.000+000	
STD OF MEAN	5.105+000	6.124-002	1.118-001	
AVE PER CENT CHANGE	-1.495+001	1.236+000	3.276-003	
INTERVAL ESTIMATE	-3.395+001	6.361-001	-1.125+000	
AS PER CENT	7.222+000	1.837+000	1.125+000	
PER CENT AVE CHANGE	-1.336+001	1.237+000	0.000+000	
GROUP S				
NUMBER	5	5	5	
INITIAL MEAN	3.026+001	1.126+001	1.110+001	
AVERAGE CHANGE	-2.700+000	2.000-001	-8.000-002	
STD OF MEAN	2.299+000	1.581-001	1.458-001	
AVE PER CENT CHANGE	-9.116+000	1.776+000	-7.207-001	
INTERVAL ESTIMATE	-1.736+001	2.170-001	-2.179+000	
AS PER CENT	-4.847-001	3.335+000	7.375-001	
PER CENT AVE CHANGE	-8.923+000	1.776+000	-7.207-001	
GROUP C				
NUMBER	5	5	5	
INITIAL MEAN	2.766+001	1.128+001	1.102+001	
AVERAGE CHANGE	4.600-001	1.000-001	4.000-002	
STD OF MEAN	2.449-001	7.906-002	1.275-001	
AVE PER CENT CHANGE	1.666+000	8.881-001	3.686-001	
INTERVAL ESTIMATE	6.797-001	1.083-001	-9.215-001	
AS PER CENT	2.646+000	1.665+000	1.647+000	
PER CENT AVE CHANGE	1.663+000	8.865-001	3.630-001	
F-TEST	2.377+000	1.886+000	2.183+000	0.000+000
T-TEST				
GROUPS P-D	1.333+000	1.562+000	-1.581+000	0.000+000
GROUPS P-S	7.340-001	6.247-001	-3.162-001	0.000+000
GROUPS P-C	-1.199+000	2.186+000	-2.214+000	
GROUPS D-S	-5.994-001	-9.370-001	1.265+000	
GROUPS D-C	-2.532+000	6.247-001	-6.325-001	
GROUPS S-C	-1.933+000	1.562+000	-1.897+000	

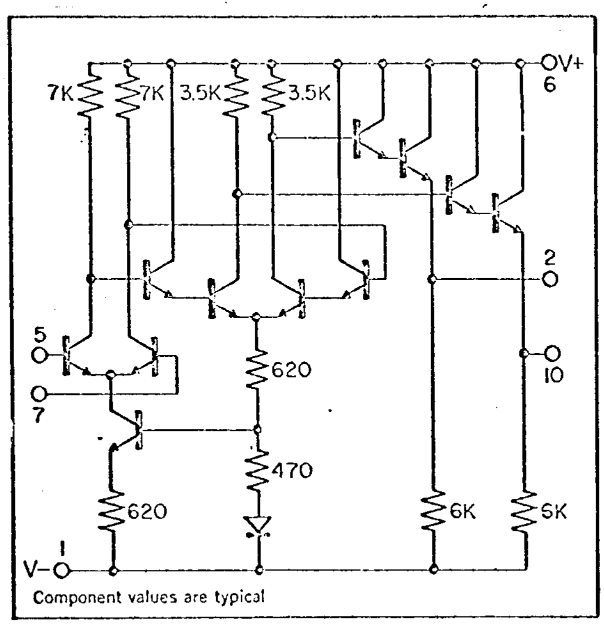
CODE μA709

	BW	I IN BIAS	V OFFSET	CMRR
UNITS	HZ	NEG AMPS	MV	DB
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	6.840+002	6.608-007	6.380-001	9.468+001
AVERAGE CHANGE	4.100+001	1.984-007	2.700-001	8.800-001
STD OF MEAN	7.679+001	1.044-007	4.459-001	1.499+000
AVE PER CENT CHANGE	6.701+000	2.984+001	6.546+000	8.937-001
INTERVAL ESTIMATE	-6.472+000	1.248+001	-3.528+001	-8.283-001
AS PER CENT	1.846+001	4.757+001	1.199+002	2.687+000
PER CENT AVE CHANGE	5.994+000	3.002+001	4.232+001	9.294-001
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	6.580+002	2.177-006	4.000-001	9.710+001
AVERAGE CHANGE	4.800+001	3.752-006	2.018+000	-1.000+000
STD OF MEAN	8.844+001	8.332-006	4.739+000	1.258+001
AVE PER CENT CHANGE	7.088+000	1.146+002	2.137+002	1.578-001
INTERVAL ESTIMATE	-7.630+000	-2.527+002	-8.111+002	-1.542+001
AS PER CENT	2.222+001	5.974+002	1.820+003	1.336+001
PER CENT AVE CHANGE	7.295+000	1.724+002	5.045+002	-1.030+000
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	6.676+002	5.438-007	1.176+000	9.924+001
AVERAGE CHANGE	3.140+001	3.108-007	2.032+000	-3.340+000
STD OF MEAN	6.459+001	2.773-007	2.509+000	5.430+000
AVE PER CENT CHANGE	4.905+000	6.111+001	6.753+001	-3.370+000
INTERVAL ESTIMATE	-6.039+000	5.328-001	-6.414+001	-9.441+000
AS PER CENT	1.545+001	1.138+002	4.097+002	2.710+000
PER CENT AVE CHANGE	4.703+000	5.715+001	1.728+002	-3.366+000
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	7.170+002	5.536-007	7.040-001	9.942+001
AVERAGE CHANGE	8.000+000	1.008-007	1.000-002	6.000-001
STD OF MEAN	5.297+001	1.660-007	2.622-002	1.696+000
AVE PER CENT CHANGE	1.359+000	2.202+001	1.065+000	6.670-001
INTERVAL ESTIMATE	-7.088+000	-1.508+001	-2.715+000	-1.290+000
AS PER CENT	9.320+000	5.149+001	5.556+000	2.497+000
PER CENT AVE CHANGE	1.116+000	1.821+001	1.420+000	6.035-001
F-TEST	3.677-001	1.134+000	1.032+000	4.858-001
T-TEST				
GROUPS P-D	-1.720-001	-1.507+000	-1.149+000	4.786-001
GROUPS P-S	2.359-001	-4.766-002	-1.158+000	1.074+000
GROUPS P-C	8.110-001	4.138-002	1.708-001	7.128-002
GROUPS D-S	4.080-001	1.459+000	-9.199-003	5.957-001
GROUPS D-C	9.830-001	1.548+000	1.319+000	-4.073-001
GROUPS S-C	5.751-001	8.904-002	1.329+000	-1.003+000

TEST RESULT SUMMARY SHEET

Circuit Identification Code: SE505G

Circuit Diagram:



Circuit Description:

Function: Differential Amplifier
Process: Planar Epitaxial
Gain: 1,800 Typical

TEST RESULT SUMMARY SHEET (Continued)

Code SE505G

IN SITE DATA

Electron Fluence:
To First Failure 6×10^{13} e/cm^2
Test Total 4.3×10^{14} e/cm^2

Failure Mode: Decrease in closed loop gain** greater than 5%

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	61 F	78 F	63 F	
$+V_{SAT}$	Mean Value Volts	2.6	2.5	2.5	2.3
	Percent Change in Mean Value (%)		3.8	3.8	11.5
	Spread min./max.	2.5/2.6	2.4/2.5	2.4/2.5	2.2/2.3
$-V_{SAT}$	Mean Value Volts	1.7	1.5	1.5	1.5
	Percent Change in Mean Value (%)		11.8	11.8	11.8
	Spread min./max.	1.7/1.7	1.2/1.7	1.3/1.6	1.3/1.6
Pulsed Circuits	Temperature	58 F	77 F	59 F	
$+ V_{SAT}$ Static Mode	Mean Value (Volts)	2.5	----	2.5*	2.3*
	Percent Change in Mean Value (%)	----	----	0	8
	Spread min./max. (Volts)	2.5/2.5	----	2.5/2.5	2.3/2.3
$+ V_{SAT}$ Pulsed Mode	Mean Value (Volts)	2.72	2.72	----	2.76
	Percent Change in Mean Value (%)	----	0	----	1.5
	Spread min./max. (Volts)	2.58/2.74	2.58/2.74	----	2.70/2.84
Dynamic Circuits	Temperature	60 F	68 F	62 F	
Relative gain (closed loop)	Percent Change from initial Value (%)	----	----	9%	----

*After 15 minutes continuous operation.
**Closed loop gain initially 85.

TEST RESULT SUMMARY SHEET (Continued)

Code SE505G

IN SITE DATA

Electron Fluence:
To First Failure 6×10^{13} e/cm^2
Test Total 4.3×10^{14} e/cm^2

Failure Mode: Decrease in closed loop gain** greater than 5%

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	61 F	78 F	63 F	
Gain	Mean Value	84.7	77.3	80.8	81.5
	Percent Change in Mean Value	----	-8.7	-4.6	-3.8
	Spread min./max.	77.3/92.8	77.3/77.3	77.2/90.2	77.3/82.5
V_{offset}	Mean Value (Volts x 10^{-3})	8.7	12.9	11.0	13.9
	Percent Change in Mean Value (%)	----	48.2	26.4	59.8
	Spread min./max.	5.6/12.0	7.1/16.2	6.9/13.8	9.1/16.7
Pulsed Circuits	Temperature	58 F	77 F	59 F	
Gain Static Mode	Mean Value	80.5	----	67.0*	70*
	Percent Change in Mean Value	----	----	-16.8	-13.0
	Spread min./max.	65.0/87.5	----	50.0/80.0	60.0/75.0
V_{offset} Static Mode	Mean Value (Volts x 10^{-3})	13	----	14	14
	Percent Change in Mean Value	----		7.6	7.6
	Spread min./max. (Volts x 10^{-3})	10/15	----	13/15	13/17
Dynamic Circuits	Temperature	60 F	68 F	62 F	

*After 15 minutes continuous operation.
**Closed loop gain initially 85.

CODE SE505G

	1 IN BIAS	GAIN	R-1,2	R-1,10
UNITS	AMPS		K OHMS	K OHMS
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	-2.754-005	3.733+003	2.996+000	3.013+000
AVERAGE CHANGE	-3.622-005	-1.120+003	5.000-002	4.960-002
STD OF MEAN	2.210-006	1.757+002	1.093-002	7.730-003
AVE PER CENT CHANGE	1.324+002	-2.995+001	1.675+000	1.647+000
INTERVAL ESTIMATE	1.404+002	-3.524+001	1.264+000	1.361+000
AS PER CENT	1.226+002	-2.479+001	2.074+000	1.931+000
PER CENT AVE CHANGE	1.315+002	-3.001+001	1.669+000	1.646+000
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	-2.676-005	3.750+003	3.097+000	3.096+000
AVERAGE CHANGE	-3.342-005	-9.582+002	4.400-002	4.760-002
STD OF MEAN	4.766-006	7.267+001	1.052-002	6.403-003
AVE PER CENT CHANGE	1.253+002	-2.555+001	1.418+000	1.545+000
INTERVAL ESTIMATE	1.447+002	-2.770+001	1.044+000	1.308+000
AS PER CENT	1.051+002	-2.340+001	1.798+000	1.767+000
PER CENT AVE CHANGE	1.249+002	-2.555+001	1.421+000	1.537+000
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	-2.816-005	3.791+003	3.251+000	3.273+000
AVERAGE CHANGE	-3.066-005	-1.034+003	1.972-001	1.966-001
STD OF MEAN	3.819-006	2.629+002	3.562-001	3.391-001
AVE PER CENT CHANGE	1.103+002	-2.705+001	6.655+000	6.524+000
INTERVAL ESTIMATE	1.239+002	-3.497+001	-6.100+000	-5.497+000
AS PER CENT	9.382+001	-1.957+001	1.823+001	1.751+001
PER CENT AVE CHANGE	1.089+002	-2.727+001	6.067+000	6.006+000
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	-2.868-005	3.777+003	3.144+000	3.168+000
AVERAGE CHANGE	5.200-007	0.000+000	-1.360-002	-1.340-002
STD OF MEAN	3.482-007	0.000+000	3.674-003	4.783-003
AVE PER CENT CHANGE	-1.814+000	0.000+000	-4.439-001	-4.326-001
INTERVAL ESTIMATE	-4.650-001	0.000+000	-5.623-001	-5.907-001
AS PER CENT	-3.161+000	0.000+000	-3.028-001	-2.554-001
PER CENT AVE CHANGE	-1.813+000	0.000+000	-4.325-001	-4.230-001
F-TEST	1.734+002	6.494+001	1.590+000	1.730+000
T-TEST				
GROUPS P-D	-1.522+000	-1.767+000	5.950-002	2.084-002
GROUPS P-S	-3.022+000	-9.436-001	-1.460+000	-1.532+000
GROUPS P-C	-1.997+001	-1.221+001	6.307-001	6.565-001
GROUPS D-S	-1.500+000	8.238-001	-1.519+000	-1.553+000
GROUPS D-C	-1.845+001	-1.044+001	5.712-001	6.357-001
GROUPS S-C	-1.695+001	-1.126+001	2.091+000	2.188+000

CODE SE505G

UNITS	V SAT 2+ VOLTS	V SAT 2- VOLTS	V SAT 10+ VOLTS	V SAT 10- VOLTS
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	2.620+000	1.680+000	2.680+000	1.700+000
AVERAGE CHANGE	8.000-002	1.200-001	1.200-001	1.000-001
STD OF MEAN	1.458-001	5.000-002	5.000-002	6.743-007
AVE PER CENT CHANGE	3.269+000	7.206+000	4.501+000	5.882+000
INTERVAL ESTIMATE	-3.125+000	3.838+000	2.406+000	5.882+000
AS PER CENT	9.232+000	1.045+001	6.549+000	5.882+000
PER CENT AVE CHANGE	3.053+000	7.143+000	4.478+000	5.882+000
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	2.700+000	1.700+000	2.700+000	1.700+000
AVERAGE CHANGE	0.000+000	1.000-001	1.000-001	1.000-001
STD OF MEAN	0.000+000	6.743-007	6.743-007	6.743-007
AVE PER CENT CHANGE	0.000+000	5.882+000	3.704+000	5.882+000
INTERVAL ESTIMATE	0.000+000	5.882+000	3.704+000	5.882+000
AS PER CENT	0.000+000	5.882+000	3.704+000	5.882+000
PER CENT AVE CHANGE	0.000+000	5.882+000	3.704+000	5.882+000
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	2.660+000	1.680+000	2.620+000	1.700+000
AVERAGE CHANGE	-2.000-002	1.200-001	1.200-001	1.000-001
STD OF MEAN	1.837-001	5.000-002	5.000-002	6.743-007
AVE PER CENT CHANGE	-7.977-001	7.206+000	4.589+000	5.882+000
INTERVAL ESTIMATE	-8.421+000	3.838+000	2.461+000	5.882+000
AS PER CENT	6.917+000	1.045+001	6.699+000	5.882+000
PER CENT AVE CHANGE	-7.519-001	7.143+000	4.580+000	5.882+000
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	2.700+000	1.700+000	2.690+000	1.750+000
AVERAGE CHANGE	6.000-002	1.000-001	9.000-002	7.000-002
STD OF MEAN	6.124-002	6.743-007	2.500-002	5.000-002
AVE PER CENT CHANGE	2.222+000	5.882+000	3.340+000	4.101+000
INTERVAL ESTIMATE	-2.962-001	5.882+000	2.314+000	8.274-001
AS PER CENT	4.741+000	5.882+000	4.378+000	7.173+000
PER CENT AVE CHANGE	2.222+000	5.882+000	3.346+000	4.000+000
F-TEST	9.645-001	6.667-001	1.000+000	2.250+000
T-TEST				
GROUPS P-D	1.167+000	1.000+000	9.428-001	0.000+000
GROUPS P-S	1.459+000	0.000+000	-5.145-010	0.000+000
GROUPS P-C	2.917-001	1.000+000	1.414+000	2.121+000
GROUPS D-S	2.917-001	-1.000+000	-9.428-001	0.000+000
GROUPS D-C	-8.752-001	0.000+000	4.714-001	2.121+000
GROUPS S-C	-1.167+000	1.000+000	1.414+000	2.121+000

CODE SE505G

UNITS	DISTORTION PER CENT	BAL OUT DC VOLTS	BW MHZ	V OFFSET VOLTS
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	2.680+000	5.160-001	1.220+000	-1.178-003
AVERAGE CHANGE	-1.800-001	-5.400-002	5.580-001	-2.670-003
STD OF MEAN	2.424-001	2.574-002	6.490-002	8.506-004
AVE PER CENT CHANGE	-6.032+000	-1.047+001	4.680+001	4.104+002
INTERVAL ESTIMATE	-1.676+001	-1.600+001	3.983+001	3.068+002
AS PER CENT	3.326+000	-4.926+000	5.165+001	1.465+002
PER CENT AVE CHANGE	-6.716+000	-1.047+001	4.574+001	2.267+002
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	2.940+000	5.160-001	1.388+000	-1.072-003
AVERAGE CHANGE	-1.200-001	-3.000-002	5.520-001	-2.596-003
STD OF MEAN	2.424-001	3.953-002	1.273-001	8.006-004
AVE PER CENT CHANGE	-3.555+000	-5.920+000	4.028+001	3.080+002
INTERVAL ESTIMATE	-1.324+001	-1.432+001	2.958+001	3.251+002
AS PER CENT	5.073+000	2.692+000	4.996+001	1.592+002
PER CENT AVE CHANGE	-4.082+000	-5.814+000	3.977+001	2.422+002
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	2.700+000	5.206-001	1.240+000	-1.552-003
AVERAGE CHANGE	-1.600-001	-1.660-002	5.760-001	-2.038-003
STD OF MEAN	3.122-001	4.349-002	2.395-001	7.936-004
AVE PER CENT CHANGE	-5.218+000	-3.109+000	4.654+001	2.038+002
INTERVAL ESTIMATE	-1.877+001	-1.246+001	2.501+001	1.881+002
AS PER CENT	6.916+000	6.087+000	6.790+001	7.453+001
PER CENT AVE CHANGE	-5.926+000	-3.189+000	4.645+001	1.313+002
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	2.840+000	5.080-001	1.312+000	-1.484-003
AVERAGE CHANGE	4.000-002	3.400-002	-6.600-002	-2.420-004
STD OF MEAN	1.000-001	3.500-002	6.643-002	7.586-004
AVE PER CENT CHANGE	1.549+000	6.944+000	-5.850+000	1.545+002
INTERVAL ESTIMATE	-2.501+000	-9.575-001	-1.065+001	7.307+001
AS PER CENT	5.318+000	1.434+001	5.915-001	-4.045+001
PER CENT AVE CHANGE	1.408+000	6.693+000	-5.030+000	1.631+001
F-TEST	1.107+000	6.457+000	3.002+001	1.247+001
T-TEST				
GROUPS P-D	-4.472-001	-1.161+000	7.400-002	-1.632-001
GROUPS P-S	-1.491-001	-1.809+000	-2.220-001	-1.394+000
GROUPS P-C	-1.640+000	-4.257+000	7.695+000	-5.355+000
GROUPS D-S	2.981-001	-6.483-001	-2.960-001	-1.231+000
GROUPS D-C	-1.193+000	-3.096+000	7.622+000	-5.192+000
GROUPS S-C	-1.491+000	-2.448+000	7.917+000	-3.961+000

CODE SE505G

CMRR

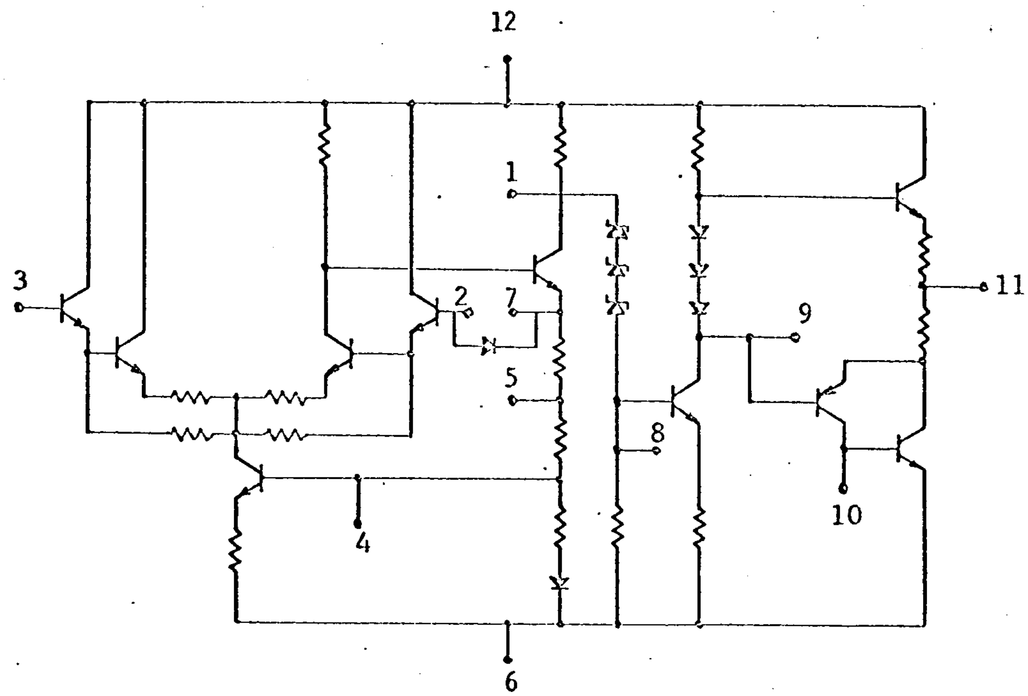
UNITS

GROUP P				
NUMBER	5			
INITIAL MEAN	6.568+001			
AVERAGE CHANGE	-5.200-001			
STD OF MEAN	2.550-001			
AVE PER CENT CHANGE	-7.914-001			
INTERVAL ESTIMATE	-1.223+000			
AS PER CENT	-3.607-001			
PER CENT AVE CHANGE	-7.917-001			
GROUP D				
NUMBER	5			
INITIAL MEAN	6.554+001			
AVERAGE CHANGE	-1.180+000			
STD OF MEAN	2.019+000			
AVE PER CENT CHANGE	-1.802+000			
INTERVAL ESTIMATE	-5.222+000			
AS PER CENT	1.621+000			
PER CENT AVE CHANGE	-1.800+000			
GROUP S				
NUMBER	5			
INITIAL MEAN	6.566+001			
AVERAGE CHANGE	-6.400-001			
STD OF MEAN	7.441-001			
AVE PER CENT CHANGE	-9.726-001			
INTERVAL ESTIMATE	-2.233+000			
AS PER CENT	2.837-001			
PER CENT AVE CHANGE	-9.747-001			
GROUP C				
NUMBER	5			
INITIAL MEAN	6.568+001			
AVERAGE CHANGE	-2.800-001			
STD OF MEAN	2.894-001			
AVE PER CENT CHANGE	-4.268-001			
INTERVAL ESTIMATE	-9.156-001			
AS PER CENT	6.295-002			
PER CENT AVE CHANGE	-4.263-001			
F-TEST	7.578-001	0.000+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	1.067+000	0.000+000	0.000+000	0.000+000
GROUPS P-S	1.941-001	0.000+000	0.000+000	0.000+000
GROUPS P-C	-3.851-001			
GROUPS D-S	-8.732-001			
GROUPS D-C	-1.455+000			
GROUPS S-C	-5.822-001			

TEST RESULT SUMMARY SHEET

Circuit Identification Code: Amelco A13251

Circuit Diagram:



Circuit Description:

Function: Operational Amplifier
Process: Planar Diffused
Gain: 20,000

TEST RESULT SUMMARY SHEET (Continued)

Code A13251

IN SITE DATA

Electron Fluence:
- To First Failure $< 10^{12}$ e/cm^2
- Test Total 3.7×10^{14} e/cm^2

Failure Mode: Closed loop gain decreased more than 5 percent

Monitored Parameters:		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	77 F	130 F	72 F	
Gain	Mean Value	148.5	47.5	42.0	42.0
	Percent Change in Mean Value (%)	----	- 68	-71.7	-71.7
	Spread min./max.	141.2/151.2	42.5/57.5	37.5/47.5	37.5/45.0
V_{offset}	Mean Value (Volts x 10^{-3})	6.2	82.9	94.2	93.7
	Percent Change in Mean Value (%)	----	1237.0	1419.3	1411.3
	Spread min./max.	2.4/12.0	52.9/100.0	83.1/114.1	85.0/108.8
Pulsed Circuits	Temperature	60 F	95 F	67 F	
Gain Static Mode	Mean Value	101.5	----	103.7*	96.2*
	Percent Change in Mean Value (%)	----	----	+2.2	-5.2
	Spread min./max.	97.5/105.0	----	102.5/105.0	95.0/97.5
V_{offset} Static Mode (absolute Value)	Mean Value (Volts x 10^{-3})	7.4		8.9*	8.6*
	Percent Change in Mean Value (%)	----		20.3	16.2
	Spread min./max. (Volts x 10^{-3})	-9.0/+7.6	----	-11.4/+5.4	-12.6/+3.6
Dynamic Circuits	Temperature	73 F	118 F	70 F	
Relative Gain (Open Loop)	Percent Change from Initial Value (%)	----	----	-90	----

*After 15 minutes continuous operation.

TEST RESULT SUMMARY SHEET (Continued)

Code A13251

IN SITE DATA

Electron Fluence:
- To First Failure $< 10^{12}$ e/cm^2
- Test Total 3.7×10^{14} e/cm^2

Failure Mode: Closed loop gain decreased more than 5 percent

Monitored Parameters:		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	77 F	130 F	72 F	
Positive V_{SAT}	Mean Value	7.6	6.2	7.2	6.8
	Percent Change in Mean Value (%)	----	-18.4	-5.3	-10.5
	Spread min./max.	7.4/7.7	5.7/6.6	7.0/7.3	6.5/6.9
Negative V_{SAT}	Mean Value	8.6	7.9	8.0	7.5
	Percent Change in Mean Value (%)	----	-8.1	-7.0	-12.8
	Spread min./max.	8.6/8.7	7.8/8.0	7.9/8.0	7.4/7.6
Pulsed Circuits	Temperature	60 F	95 F	67 F	
Positive V_{SAT} Static Mode	Mean Value (Volts)	11.1	----	10.9*	10.6*
	Percent Change in Mean Value (%)	----	----	-2.7	-4.5
	Spread min./max. (Volts)	10.4/11.2	----	10.2/11.2	10.0/10.9
Positive V_{SAT} Pulsed Mode	Mean Value (Volts)	7.7	9.4	----	11.6
	Percent Change in Mean Value (%)	----	22		51
	Spread min./max. (Volts)	5.7/8.9	5.0/11.0	----	11.3/11.9
Dynamic Circuits	Temperature				

CODE A13-251

	VSAT-	VSAT+	GAIN	BW
UNITS	VOLTS	VOLTS		KHZ
GROUP P				
NUMBER	4	5	4	4
INITIAL MEAN	1.000+001	1.100+001	1.752+004	1.950+000
AVERAGE CHANGE	0.000+000	0.000+000	-7.075+003	6.000+000
STD OF MEAN	0.000+000	0.000+000	1.072+003	5.709+000
AVE PER CENT CHANGE	0.000+000	0.000+000	-4.512+001	2.708+002
INTERVAL ESTIMATE	0.000+000	0.000+000	-4.882+001	-9.570+001
AS PER CENT	0.000+000	0.000+000	-3.195+001	7.111+002
PER CENT AVE CHANGE	0.000+000	0.000+000	-4.038+001	3.077+002
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	1.000+001	1.100+001	2.000+004	1.728+000
AVERAGE CHANGE	0.000+000	0.000+000	-6.860+003	3.222+000
STD OF MEAN	0.000+000	0.000+000	8.610+002	3.526-001
AVE PER CENT CHANGE	0.000+000	0.000+000	-3.430+001	1.869+002
INTERVAL ESTIMATE	0.000+000	0.000+000	-3.908+001	1.638+002
AS PER CENT	0.000+000	0.000+000	-2.952+001	2.091+002
PER CENT AVE CHANGE	0.000+000	0.000+000	-3.430+001	1.865+002
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	1.000+001	1.100+001	2.016+004	1.654+000
AVERAGE CHANGE	0.000+000	0.000+000	-6.740+003	3.006+000
STD OF MEAN	0.000+000	0.000+000	6.354+002	3.826-001
AVE PER CENT CHANGE	0.000+000	0.000+000	-3.345+001	1.814+002
INTERVAL ESTIMATE	0.000+000	0.000+000	-3.693+001	1.561+002
AS PER CENT	0.000+000	0.000+000	-2.993+001	2.074+002
PER CENT AVE CHANGE	0.000+000	0.000+000	-3.343+001	1.817+002
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	1.000+001	1.100+001	1.890+004	1.838+000
AVERAGE CHANGE	0.000+000	0.000+000	-2.000+001	4.000-003
STD OF MEAN	0.000+000	0.000+000	2.000+002	1.000-002
AVE PER CENT CHANGE	0.000+000	0.000+000	-6.854-002	1.869-001
INTERVAL ESTIMATE	0.000+000	0.000+000	-1.281+000	-3.865-001
AS PER CENT	0.000+000	0.000+000	1.069+000	8.218-001
PER CENT AVE CHANGE	0.000+000	0.000+000	-1.058-001	2.176-001
F-TEST	0.000+000	0.000+000	1.360+002	5.455+000
T-TEST				
GROUPS P-D	0.000+000	0.000+000	-4.915-001	1.862+000
GROUPS P-S	0.000+000	0.000+000	-7.658-001	2.007+000
GROUPS P-C	0.000+000	0.000+000	-1.613+001	4.019+000
GROUPS D-S	0.000+000	0.000+000	-2.909-001	1.536-001
GROUPS D-C	0.000+000	0.000+000	-1.658+001	2.288+000
GROUPS S-C	0.000+000	0.000+000	-1.629+001	2.134+000

CODE A13-251

	I IN BIAS	V OFFSET	R68	CMRR
UNITS	AMPS	MV	OHMS	DB
GROUP P				
NUMBER	5	4	5	4
INITIAL MEAN	6.348-007	3.826+000	3.478+004	6.966+001
AVERAGE CHANGE	1.129-004	2.385+000	1.980+003	7.550+000
STD OF MEAN	2.773-004	4.743-001	3.102+002	3.624+000
AVE PER CENT CHANGE	2.165+004	2.059+001	5.838+000	1.079+001
INTERVAL ESTIMATE	-3.072+004	4.526+001	4.702+000	3.670+000
AS PER CENT	6.628+004	7.942+001	6.683+000	1.801+001
PER CENT AVE CHANGE	1.778+004	6.234+001	5.693+000	1.084+001
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	5.678-007	5.692+000	3.566+004	6.954+001
AVERAGE CHANGE	2.003-006	3.114+000	2.340+003	6.440+000
STD OF MEAN	2.415-007	1.423+000	9.798+002	1.193+000
AVE PER CENT CHANGE	3.558+002	4.419+002	6.461+000	9.256+000
INTERVAL ESTIMATE	3.055+002	2.694+001	3.511+000	7.356+000
AS PER CENT	4.000+002	8.247+001	9.613+000	1.117+001
PER CENT AVE CHANGE	3.527+002	5.471+001	6.562+000	9.261+000
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	4.852-007	6.946+000	4.110+004	6.952+001
AVERAGE CHANGE	1.795-006	2.422+000	3.960+003	6.620+000
STD OF MEAN	2.043-007	1.400+000	6.354+002	1.829+000
AVE PER CENT CHANGE	3.719+002	4.379+001	9.617+000	9.509+000
INTERVAL ESTIMATE	3.232+002	1.249+001	7.918+000	6.601+000
AS PER CENT	4.167+002	5.725+001	1.135+001	1.244+001
PER CENT AVE CHANGE	3.700+002	3.487+001	9.635+000	9.522+000
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	4.660-007	6.338+000	4.912+004	6.912+001
AVERAGE CHANGE	8.800-009	5.740-001	-1.280+003	6.400+000
STD OF MEAN	1.629-008	2.183-001	4.214+003	3.107+000
AVE PER CENT CHANGE	1.756+000	1.070+001	-9.872-001	9.231+000
INTERVAL ESTIMATE	-1.992+000	5.232+000	-1.213+001	4.267+000
AS PER CENT	5.769+000	1.288+001	6.921+000	1.425+001
PER CENT AVE CHANGE	1.888+000	9.056+000	-2.606+000	9.259+000
F-TEST	1.013+000	6.572+000	6.273+000	2.449-001
T-TEST				
GROUPS P-D	1.414+000	-1.149+000	-2.903-001	7.365-001
GROUPS P-S	1.416+000	-5.833-002	-1.597+000	6.171-001
GROUPS P-C	1.439+000	2.855+000	2.629+000	7.631-001
GROUPS D-S	2.647-003	1.157+000	-1.306+000	-1.267-001
GROUPS D-C	2.543-002	4.247+000	2.919+000	2.815-002
GROUPS S-C	2.278-002	3.090+000	4.226+000	1.548-001

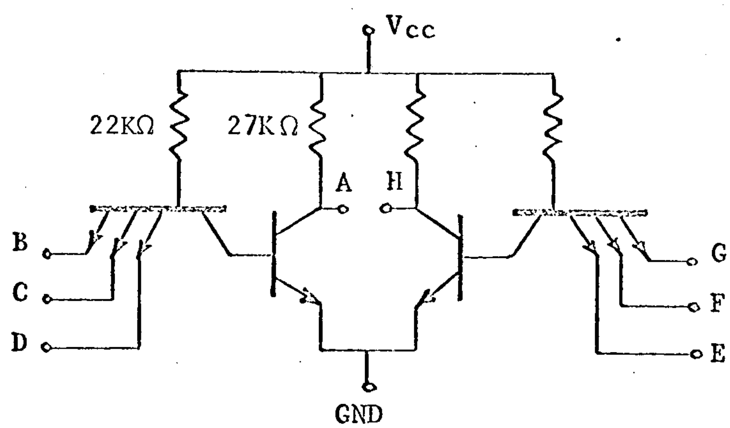
CODE A13-251

	HFE NPN	HFE PNP		
UNITS				
GROUP P				
NUMBER	4	4		
INITIAL MEAN	1.318+002	7.752+000		
AVERAGE CHANGE	-6.775+001	-9.105+000		
STD OF MEAN	8.863+000	3.221+000		
AVE PER CENT CHANGE	-5.086+001	-9.708+001		
INTERVAL ESTIMATE	-6.067+001	-1.747+002		
AS PER CENT	-4.214+001	-6.020+001		
PER CENT AVE CHANGE	-5.140+001	-1.175+002		
GROUP D				
NUMBER	4	5		
INITIAL MEAN	1.372+002	8.310+000		
AVERAGE CHANGE	-7.150+001	-7.956+000		
STD OF MEAN	6.700+000	1.589+000		
AVE PER CENT CHANGE	-5.096+001	-9.578+001		
INTERVAL ESTIMATE	-5.884+001	-1.170+002		
AS PER CENT	-4.539+001	-7.450+001		
PER CENT AVE CHANGE	-5.211+001	-9.574+001		
GROUP S				
NUMBER	5	5		
INITIAL MEAN	1.510+002	9.138+000		
AVERAGE CHANGE	-7.440+001	-8.792+000		
STD OF MEAN	1.389+001	1.616+000		
AVE PER CENT CHANGE	-4.917+001	-9.625+001		
INTERVAL ESTIMATE	-5.948+001	-1.159+002		
AS PER CENT	-3.906+001	-7.657+001		
PER CENT AVE CHANGE	-4.927+001	-9.621+001		
GROUP C				
NUMBER	3	5		
INITIAL MEAN	1.654+002	7.590+000		
AVERAGE CHANGE	-1.800+001	0.000+000		
STD OF MEAN	1.592+001	0.000+000		
AVE PER CENT CHANGE	-9.547+000	0.000+000		
INTERVAL ESTIMATE	-3.041+001	0.000+000		
AS PER CENT	8.644+000	0.000+000		
PER CENT AVE CHANGE	-1.088+001	0.000+000		
F-TEST	2.292+001	3.452+001	0.000+000	0.000+000
T-TEST				
GROUPS P-D	5.232-001	-1.052+000	0.000+000	0.000+000
GROUPS P-S	9.780-001	-2.865-001	0.000+000	0.000+000
GROUPS P-C	-6.426+000	-8.334+000		
GROUPS D-S	4.265-001	8.116-001		
GROUPS D-C	-6.911+000	-7.724+000		
GROUPS S-C	-7.619+000	-8.536+000		

TEST RESULT SUMMARY SHEET

Circuit Identification Code: Philco PL987

Circuit Diagram:



Circuit Description:

Function: Micropower NAND Gate
Process: Planar Epitaxial
Advertised Speed: Average Propagation Delay
75 ns Typical
120 ns Maximum

TEST RESULT SUMMARY SHEET (Continued) Code PL987

IN SITE DATA

Electron Fluence:
To First Failure 1.45×10^{15} e/cm^2
Test Total 1.45×10^{15} e/cm^2

Failure Mode: V_{zero} exceeded 0.215 Volts

Monitored Parameters:		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	78 F	82 F	74 F	
V_{zero}	Mean Value (Volts)	.173	.197	.199	.198
	Percent Change in Mean Value (%)	----	13.9	15.0	14.4
	Spread min./max.	.156/.190	.180/.210	.180/.215	.180/.214
V_{one}	Mean Value (Volts)	2.55	2.51	2.51	2.53
	Percent Change in Mean Value (%)	----	-1.6	-1.6	-1.6
	Spread min./max.	2.53/2.57	2.49/2.52	2.49/2.52	2.52/2.55
Pulsed Circuits	Temperature (Thermocouple was not	in contact	with microcircuit)		
V_{zero} Static Mode	Mean Value (Volts)	.165	----	.197*	.224*
	Percent Change in Mean Value (%)	----	----	19.4	35.7
	Spread min./max.	.155/.176	----	.178/.209	.205/.236
V_{zero} Pulsed Mode	Mean Value (Volts)	.200	.236	----	.219
	Percent Change in Mean Value (%)	----	18	----	9.5
	Spread min./max.	.178/.214	.214/.250	----	.193/.241
Dynamic Circuits	Temperature	74 F	82 F	74 F	
Multistage Propagation Delay	Mean Value (f^{-1} ns)	250	330	330	310
	Percent Change in Mean Value (%)	----	32	32	24

*After 15 minutes continuous operation.

CODE PL987

	IIN DRIVE	IIN LEAK	IPOWER-1	IPOWER-0
UNITS	AMPS	AMPS	AMP	
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	1.156-004	1.346-006	2.420-004	4.240-004
AVERAGE CHANGE	-2.600-006	-2.440-007	-2.000-006	-4.000-006
STD OF MEAN	6.124-007	1.882-007	9.354-006	1.275-005
AVE PER CENT CHANGE	-2.243+000	-1.724+001	-7.330-001	-9.090-001
INTERVAL ESTIMATE	-2.837+000	-3.365+001	-5.119+000	-4.282+000
AS PER CENT	-1.661+000	-2.603+000	3.466+000	2.395+000
PER CENT AVE CHANGE	-2.249+000	-1.813+001	-8.264-001	-9.434-001
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	1.130-004	1.606-006	2.340-004	4.160-004
AVERAGE CHANGE	-2.600-006	-3.900-007	7.105-016	-8.000-006
STD OF MEAN	6.124-007	1.789-007	1.369-005	9.354-006
AVE PER CENT CHANGE	-2.316+000	-2.369+001	3.004-002	-1.920+000
INTERVAL ESTIMATE	-2.903+000	-3.665+001	-6.498+000	-4.420+000
AS PER CENT	-1.699+000	-1.192+001	6.498+000	5.738-001
PER CENT AVE CHANGE	-2.301+000	-2.428+001	3.037-010	-1.923+000
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	1.198-004	1.514-006	2.720-004	4.220-004
AVERAGE CHANGE	-3.400-006	-2.900-007	-3.000-005	-2.000-006
STD OF MEAN	1.000-006	1.440-007	6.275-005	9.354-006
AVE PER CENT CHANGE	-2.807+000	-1.840+001	-9.003+000	-3.990-001
INTERVAL ESTIMATE	-3.765+000	-2.972+001	-3.665+001	-2.935+000
AS PER CENT	-1.911+000	-8.590+000	1.459+001	1.987+000
PER CENT AVE CHANGE	-2.838+000	-1.915+001	-1.103+001	-4.739-001
GROUP C				
NUMBER	5	5	5	4
INITIAL MEAN	1.142-004	1.208-006	2.360-004	4.125-004
AVERAGE CHANGE	-2.000-006	-1.200-008	-2.000-006	0.000+000
STD OF MEAN	1.455-011	9.354-009	5.000-006	0.000+000
AVE PER CENT CHANGE	-1.755+000	-1.182+000	-7.692-001	0.000+000
INTERVAL ESTIMATE	-1.751+000	-1.853+000	-3.200+000	0.000+000
AS PER CENT	-1.751+000	-1.335-001	1.505+000	0.000+000
PER CENT AVE CHANGE	-1.751+000	-9.934-001	-8.475-001	0.000+000
F-TEST	4.714+000	7.257+000	1.217+000	7.505-001
T-TEST				
GROUPS P-D	2.819-009	1.738+000	-1.086-001	7.454-001
GROUPS P-S	2.138+000	5.475-001	1.521+000	-3.727-001
GROUPS P-C	-1.604+000	-2.761+000	0.000+000	-7.027-001
GROUPS D-S	2.138+000	-1.190+000	1.629+000	-1.118+000
GROUPS D-C	-1.604+000	-4.499+000	1.086-001	-1.405+000
GROUPS S-C	-3.742+000	-3.309+000	-1.521+000	-3.514-001

CODE PL987

VMXZERO-4

UNITS VOLTS

GROUP P

NUMBER	15
INITIAL MEAN	5.782-001
AVERAGE CHANGE	4.353-002
STD OF MEAN	4.542-002
AVE PER CENT CHANGE	7.498+000
INTERVAL ESTIMATE	3.326+000
AS PER CENT	1.173+001
PER CENT AVE CHANGE	7.529+000

GROUP D

NUMBER	15
INITIAL MEAN	5.841-001
AVERAGE CHANGE	2.847-002
STD OF MEAN	2.479-002
AVE PER CENT CHANGE	4.869+000
INTERVAL ESTIMATE	2.603+000
AS PER CENT	7.145+000
PER CENT AVE CHANGE	4.874+000

GROUP S

NUMBER	15
INITIAL MEAN	5.753-001
AVERAGE CHANGE	3.287-002
STD OF MEAN	2.989-002
AVE PER CENT CHANGE	5.710+000
INTERVAL ESTIMATE	2.933+000
AS PER CENT	8.492+000
PER CENT AVE CHANGE	5.713+000

GROUP C

NUMBER	15
INITIAL MEAN	5.771-001
AVERAGE CHANGE	2.040-002
STD OF MEAN	1.637-002
AVE PER CENT CHANGE	3.532+000
INTERVAL ESTIMATE	2.017+000
AS PER CENT	5.053+000
PER CENT AVE CHANGE	3.535+000

F-TEST	1.557+000	0.000+000	0.000+000	0.000+000

T-TEST

GROUPS P-D	1.379+000	0.000+000	0.000+000	0.000+000
GROUPS P-S	9.760-001	0.000+000	0.000+000	0.000+000
GROUPS P-C	2.117+000			
GROUPS D-S	-4.026-001			
GROUPS D-C	7.381-001			
GROUPS S-C	1.141+000			

CODE PL987

VMINONE-4

UNITS VOLTS

GROUP P				
NUMBER	15			
INITIAL MEAN	6.061-001			
AVERAGE CHANGE	4.967-002			
STD OF MEAN	5.183-002			
AVE PER CENT CHANGE	8.204+000			
INTERVAL ESTIMATE	3.618+000			
AS PER CENT	1.277+001			
PER CENT AVE CHANGE	8.194+000			
GROUP D				
NUMBER	15			
INITIAL MEAN	6.079-001			
AVERAGE CHANGE	2.400-002			
STD OF MEAN	1.967-002			
AVE PER CENT CHANGE	3.947+000			
INTERVAL ESTIMATE	2.217+000			
AS PER CENT	5.679+000			
PER CENT AVE CHANGE	3.948+000			
GROUP S				
NUMBER	15			
INITIAL MEAN	6.013-001			
AVERAGE CHANGE	2.587-002			
STD OF MEAN	2.532-002			
AVE PER CENT CHANGE	4.298+000			
INTERVAL ESTIMATE	2.048+000			
AS PER CENT	6.555+000			
PER CENT AVE CHANGE	4.302+000			
GROUP C				
NUMBER	15			
INITIAL MEAN	6.048-001			
AVERAGE CHANGE	9.000-003			
STD OF MEAN	7.203-003			
AVE PER CENT CHANGE	1.492+000			
INTERVAL ESTIMATE	8.508-001			
AS PER CENT	2.125+000			
PER CENT AVE CHANGE	1.488+000			
F-TEST	4.824+000	0.000+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	2.371+000	0.000+000	0.000+000	0.000+000
GROUPS P-S	2.199+000	0.000+000	0.000+000	0.000+000
GROUPS P-C	3.757+000			
GROUPS D-S	-1.724-001			
GROUPS D-C	1.386+000			
GROUPS S-C	1.558+000			

CODE PL987

UNITS	VMINONE-1 VOLTS	VMXZERO-1 VOLTS	R PULL-UP K OHMS	IOUT DRIVE MA
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	5.760-001	5.564-001	6.940+000	1.428+000
AVERAGE CHANGE	2.000-003	-3.000-003	1.480-001	-5.280-001
STD OF MEAN	3.536-003	4.743-003	3.391-002	3.391-001
AVE PER CENT CHANGE	3.558-001	-5.265-001	2.136+000	-3.605+001
INTERVAL ESTIMATE	-3.344-001	-1.486+000	1.590+000	-6.334+001
AS PER CENT	1.029+000	4.075-001	2.675+000	-1.061+001
PER CENT AVE CHANGE	3.472-001	-5.392-001	2.133+000	-3.697+001
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	5.784-001	5.608-001	7.094+000	1.648+000
AVERAGE CHANGE	1.000-003	-3.400-003	1.580-001	-7.000-001
STD OF MEAN	2.236-003	2.915-003	4.138-002	1.708-001
AVE PER CENT CHANGE	1.783-001	-5.981-001	2.219+000	-4.214+001
INTERVAL ESTIMATE	-2.564-001	-1.184+000	1.579+000	-5.399+001
AS PER CENT	6.022-001	-2.900-002	2.875+000	-3.096+001
PER CENT AVE CHANGE	1.729-001	-6.063-001	2.227+000	-4.248+001
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	5.734-001	5.564-001	6.940+000	1.692+000
AVERAGE CHANGE	-2.800-003	-4.800-003	1.620-001	-7.220-001
STD OF MEAN	5.443-003	9.267-003	9.354-003	3.050-001
AVE PER CENT CHANGE	-4.804-001	-8.437-001	2.336+000	-4.188+001
INTERVAL ESTIMATE	-1.542+000	-2.712+000	2.185+000	-6.269+001
AS PER CENT	5.657-001	9.867-001	2.484+000	-2.266+001
PER CENT AVE CHANGE	-4.883-001	-8.627-001	2.334+000	-4.267+001
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	5.734-001	5.534-001	7.068+000	1.392+000
AVERAGE CHANGE	-4.000-004	4.000-004	9.400-002	-2.000-002
STD OF MEAN	2.574-003	3.122-003	6.124-003	2.372-002
AVE PER CENT CHANGE	-7.069-002	6.794-002	1.332+000	-1.518+000
INTERVAL ESTIMATE	-5.682-001	-5.543-001	1.234+000	-3.329+000
AS PER CENT	4.287-001	6.988-001	1.426+000	4.551-001
PER CENT AVE CHANGE	-6.976-002	7.228-002	1.330+000	-1.437+000
F-TEST	2.014+000	9.608-001	8.332+000	1.123+001
T-TEST				
GROUPS P-D	4.622-001	1.257-001	-6.468-001	1.247+000
GROUPS P-S	2.315+000	5.655-001	-9.056-001	1.407+000
GROUPS P-C	1.157+000	-1.068+000	3.493+000	-3.684+000
GROUPS D-S	1.833+000	4.399-001	-2.587-001	1.595-001
GROUPS D-C	6.751-001	-1.194+000	4.140+000	-4.931+000
GROUPS S-C	-1.157+000	-1.634+000	4.399+000	-5.090+000

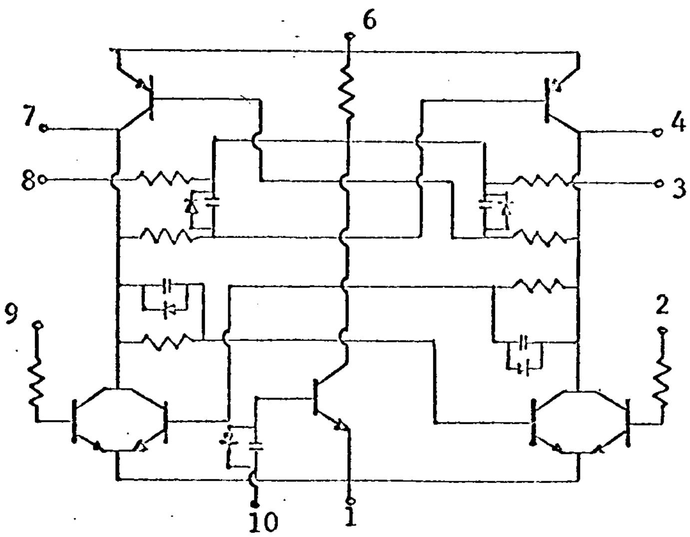
CODE PL987

	T-RISE	T-FALL	T-DELAY	T-STORE
UNITS	NS	NS	NS	NS
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	4.780+001	9.480+002	1.640+001	8.000+001
AVERAGE CHANGE	1.860+001	6.400+001	4.500+000	3.600+000
STD OF MEAN	5.397+000	3.317+001	2.500+000	2.187+001
AVE PER CENT CHANGE	3.940+001	6.717+000	2.634+001	1.059+001
INTERVAL ESTIMATE	2.638+001	2.866+000	1.051+001	-2.586+001
AS PER CENT	5.145+001	1.064+001	4.437+001	3.486+001
PER CENT AVE CHANGE	3.891+001	6.751+000	2.744+001	4.500+000
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	4.400+001	9.440+002	1.670+001	9.200+001
AVERAGE CHANGE	1.800+001	7.200+001	5.000+000	-6.800+000
STD OF MEAN	3.791+000	4.899+001	2.271+000	2.000+000
AVE PER CENT CHANGE	4.182+001	7.734+000	2.920+001	-7.436+000
INTERVAL ESTIMATE	3.134+001	1.865+000	1.484+001	-9.805+000
AS PER CENT	5.048+001	1.339+001	4.504+001	-4.977+000
PER CENT AVE CHANGE	4.091+001	7.627+000	2.994+001	-7.391+000
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	4.400+001	9.560+002	1.720+001	8.880+001
AVERAGE CHANGE	1.720+001	7.600+001	3.700+000	-2.000+000
STD OF MEAN	6.195+000	1.871+001	1.561+000	6.519+000
AVE PER CENT CHANGE	4.060+001	7.990+000	2.223+001	-2.085+000
INTERVAL ESTIMATE	2.346+001	5.777+000	1.143+001	-1.040+001
AS PER CENT	5.472+001	1.012+001	3.159+001	5.900+000
PER CENT AVE CHANGE	3.909+001	7.950+000	2.151+001	-2.252+000
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	5.060+001	9.640+002	1.670+001	9.160+001
AVERAGE CHANGE	-1.800+000	1.600+001	4.000-001	-4.000+000
STD OF MEAN	4.500+000	1.871+001	6.292-001	0.000+000
AVE PER CENT CHANGE	-3.462+000	1.659+000	2.150+000	-4.370+000
INTERVAL ESTIMATE	-1.343+001	-4.952-001	-3.118+000	-4.367+000
AS PER CENT	6.318+000	3.815+000	7.908+000	-4.367+000
PER CENT AVE CHANGE	-3.557+000	1.660+000	2.395+000	-4.367+000
F-TEST	2.391+001	4.595+000	7.375+000	9.213-001
T-TEST				
GROUPS P-D	2.099-001	-4.364-001	-4.637-001	1.605+000
GROUPS P-S	4.898-001	-6.547-001	7.420-001	8.641-001
GROUPS P-C	7.137+000	2.619+000	3.803+000	1.173+000
GROUPS D-S	2.799-001	-2.182-001	1.206+000	-7.407-001
GROUPS D-C	6.927+000	3.055+000	4.266+000	-4.320-001
GROUPS S-C	6.647+000	3.273+000	3.061+000	3.086-001

TEST RESULT SUMMARY SHEET

Circuit Identification Code: Westinghouse WS113Q

Circuit Diagram:



Circuit Description:

Function: Complementary Flip Flop
Process: Planar Epitaxial
Advertised Speed: Count Rate*
0.5 mHz Typical
1.0 mHz Maximum

*No Notching at this Rate.

TEST RESULT SUMMARY SHEET (Continued) Code WS113Q

IN SITE DATA

Electron Fluence:

To First Failure	8.0×10^{14}	e/cm^2
Test Total	9.4×10^{14}	e/cm^2

Failure Mode: V_{one} decrease to less than 2.5 Volts

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	71 F	83 F	73 F	
V_{zero}	Mean Value (Volts)	.065	.142	.140	.137
	Percent Change in Mean Value (%)	----	118.5	115.4	110.8
	Spread min./max.	.055/.079	.121/.175	.120/.170	.119/.161
V_{one}	Mean Value (Volts)	2.88	2.73	2.74	2.75
	Percent Change in Mean Value	----	-5.2	-4.9	-4.5
	Spread min./max.	2.85/2.91	2.29/2.90	2.30/2.90	2.82/2.92
Pulsed Circuits	Temperature	71 F	88 F	73 F	
V_{zero} Static Mode	Mean Value (Volts)	.058	----	.161*	.183*
	Percent Change in Mean Value (%)	----	----	177.5	215.5
	Spread min./max	.048/.079	----	.140/.205	.168/.223
V_{zero} Pulsed Mode	Mean Value (Volts)	.080	.145	----	.185
	Percent Change in Mean Value (%)	----	81.2	----	131.2
	Spread min./max.	.064/.096	.129/.193	----	.162/.225
Dynamic Circuits	Temperature	71 F	93 F	73 F	
	Measurements were not meaningful due to improper device operation				

*After 15 minutes continuous operation.

** Reset on continuously

CODE WS113Q

	I IN DRIVE	VTH		
UNITS	AMPS	VOLTS		
GROUP P				
NUMBER	10	10		
INITIAL MEAN	3.600-004	1.091+000		
AVERAGE CHANGE	-8.000-006	-1.387-001		
STD OF MEAN	2.846-005	1.564-001		
AVE PER CENT CHANGE	5.096-001	-1.099+001		
INTERVAL ESTIMATE	-7.587+000	-2.244+001		
AS PER CENT	3.142+000	-2.985+000		
PER CENT AVE CHANGE	-2.222+000	-1.271+001		
GROUP D				
NUMBER	8	8		
INITIAL MEAN	1.690-004	9.056-001		
AVERAGE CHANGE	-3.750-006	2.375-003		
STD OF MEAN	5.533-006	2.024-002		
AVE PER CENT CHANGE	-2.088+000	4.477-001		
INTERVAL ESTIMATE	-4.780+000	-1.486+000		
AS PER CENT	3.417-001	2.011+000		
PER CENT AVE CHANGE	-2.219+000	2.623-001		
GROUP S				
NUMBER	10	10		
INITIAL MEAN	1.390-004	8.153-001		
AVERAGE CHANGE	-4.000-006	-6.790-002		
STD OF MEAN	5.443-006	2.014-001		
AVE PER CENT CHANGE	-3.164+000	-8.336+000		
INTERVAL ESTIMATE	-5.535+000	-2.510+001		
AS PER CENT	-2.203-001	8.439+000		
PER CENT AVE CHANGE	-2.878+000	-8.328+000		
GROUP C				
NUMBER	10	10		
INITIAL MEAN	1.720-004	7.537-001		
AVERAGE CHANGE	-2.000-006	1.220-002		
STD OF MEAN	4.444-006	9.886-003		
AVE PER CENT CHANGE	-1.032+000	1.709+000		
INTERVAL ESTIMATE	-2.916+000	7.286-001		
AS PER CENT	5.907-001	2.509+000		
PER CENT AVE CHANGE	-1.163+000	1.619+000		
F-TEST	3.044-001	3.046+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	-6.180-001	-2.382+000	0.000+000	0.000+000
GROUPS P-S	-6.169-001	-1.268+000	0.000+000	0.000+000
GROUPS P-C	-9.253-001	-2.702+000		
GROUPS D-S	3.635-002	1.186+000		
GROUPS D-C	-2.545-001	-1.659-001		
GROUPS S-C	-3.084-001	-1.434+000		

CODE WS113Q

	IIN LEAK	IIN DRIVE		
UNITS	AMPS	AMPS		
GROUP P				
NUMBER	8	10		
INITIAL MEAN	6.960-007	6.210-005		
AVERAGE CHANGE	8.125-008	4.000-006		
STD OF MEAN	9.269-007	3.158-005		
AVE PER CENT CHANGE	2.137+002	3.451+001		
INTERVAL ESTIMATE	-9.249+001	-2.807+001		
AS PER CENT	1.158+002	4.095+001		
PER CENT AVE CHANGE	1.167+001	6.441+000		
GROUP D				
NUMBER	8	8		
INITIAL MEAN	4.143-007	6.220-005		
AVERAGE CHANGE	6.634-007	5.500-006		
STD OF MEAN	4.747-007	3.232-005		
AVE PER CENT CHANGE	4.313+002	3.632+001		
INTERVAL ESTIMATE	7.050+001	-3.180+001		
AS PER CENT	2.497+002	4.948+001		
PER CENT AVE CHANGE	1.601+002	8.842+000		
GROUP S				
NUMBER	10	10		
INITIAL MEAN	1.094-006	8.320-005		
AVERAGE CHANGE	-8.120-008	2.300-005		
STD OF MEAN	1.661-006	6.750-005		
AVE PER CENT CHANGE	2.373+002	3.278+001		
INTERVAL ESTIMATE	-1.104+002	-2.741+001		
AS PER CENT	9.559+001	8.270+001		
PER CENT AVE CHANGE	-7.421+000	2.764+001		
GROUP C				
NUMBER	10	10		
INITIAL MEAN	2.449-007	6.270-005		
AVERAGE CHANGE	2.195-006	5.400-005		
STD OF MEAN	2.212-006	4.013-005		
AVE PER CENT CHANGE	2.347+003	1.326+002		
INTERVAL ESTIMATE	2.835+002	4.269+001		
AS PER CENT	1.509+003	1.296+002		
PER CENT AVE CHANGE	8.963+002	8.612+001		
F-TEST	4.886+000	2.755+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	-7.951-001	-7.265-002	0.000+000	0.000+000
GROUPS P-S	2.339-001	-9.760-001	0.000+000	0.000+000
GROUPS P-C	-3.043+000	-2.568+000		
GROUPS D-S	1.072+000	-8.475-001		
GROUPS D-C	-2.205+000	-2.349+000		
GROUPS S-C	-3.476+000	-1.592+000		

CODE WS113Q

	UNITS	VTH VOLTS	VA VOLTS		
GROUP P					
NUMBER		10	5		
INITIAL MEAN		2.175+000	8.740-001		
AVERAGE CHANGE		-2.869-001	2.340-001		
STD OF MEAN		2.889-001	7.608-002		
AVE PER CENT CHANGE		-1.199+001	2.684+001		
INTERVAL ESTIMATE		-2.220+001	1.711+001		
AS PER CENT		-4.176+000	3.644+001		
PER CENT AVE CHANGE		-1.319+001	2.677+001		
GROUP D					
NUMBER		7	1		
INITIAL MEAN		2.892+000	9.000-001		
AVERAGE CHANGE		-1.112+000	2.200-001		
STD OF MEAN		4.040-001	0.000+000		
AVE PER CENT CHANGE		-3.419+001	2.619+001		
INTERVAL ESTIMATE		-5.043+001	2.444+001		
AS PER CENT		-2.650+001	2.444+001		
PER CENT AVE CHANGE		-3.847+001	2.444+001		
GROUP S					
NUMBER		10	3		
INITIAL MEAN		2.587+000	8.400-001		
AVERAGE CHANGE		-6.078-001	2.433-001		
STD OF MEAN		3.778-001	9.975-002		
AVE PER CENT CHANGE		-2.347+001	2.932+001		
INTERVAL ESTIMATE		-3.340+001	4.880+000		
AS PER CENT		-1.358+001	5.306+001		
PER CENT AVE CHANGE		-2.349+001	2.897+001		
GROUP C					
NUMBER		9	1		
INITIAL MEAN		2.939+000	9.550-001		
AVERAGE CHANGE		-1.260-001	1.100-001		
STD OF MEAN		1.117-001	0.000+000		
AVE PER CENT CHANGE		-4.657+000	1.183+001		
INTERVAL ESTIMATE		-7.042+000	1.152+001		
AS PER CENT		-1.532+000	1.152+001		
PER CENT AVE CHANGE		-4.287+000	1.152+001		
F-TEST		1.721+001	9.201-001	0.000+000	0.000+000
T-TEST					
GROUPS P-D		5.703+000	1.756-001	0.000+000	0.000+000
GROUPS P-S		2.443+000	-1.756-001	0.000+000	0.000+000
GROUPS P-C		-1.192+000	1.555+000		
GROUPS D-S		-3.486+000	-2.776-001		
GROUPS D-C		-6.664+000	1.069+000		
GROUPS S-C		-3.570+000	1.586+000		

CODE WS1130

UNITS	V SAT VOLTS	I-POWER AMPS		
GROUP P				
NUMBER	5	5		
INITIAL MEAN	9.200-003	1.500-004		
AVERAGE CHANGE	4.780-002	-8.000-006		
STD OF MEAN	9.598-003	5.000-006		
AVE PER CENT CHANGE	5.726+002	-5.455+000		
INTERVAL ESTIMATE	4.037+002	-9.035+000		
AS PER CENT	6.354+002	-1.632+000		
PER CENT AVE CHANGE	5.196+002	-5.333+000		
GROUP D				
NUMBER	4	4		
INITIAL MEAN	6.200-003	1.320-004		
AVERAGE CHANGE	4.300-002	-5.000-006		
STD OF MEAN	7.242-003	1.155-005		
AVE PER CENT CHANGE	9.200+002	-4.006+000		
INTERVAL ESTIMATE	5.326+002	-1.584+001		
AS PER CENT	8.545+002	8.265+000		
PER CENT AVE CHANGE	6.935+002	-3.788+000		
GROUP S				
NUMBER	5	5		
INITIAL MEAN	5.000-003	1.240-004		
AVERAGE CHANGE	3.540-002	-1.800-005		
STD OF MEAN	8.500-003	1.458-005		
AVE PER CENT CHANGE	7.100+002	-1.481+001		
INTERVAL ESTIMATE	5.192+002	-2.757+001		
AS PER CENT	8.968+002	-1.462+000		
PER CENT AVE CHANGE	7.080+002	-1.452+001		
GROUP C				
NUMBER	5	5		
INITIAL MEAN	1.000-002	1.390-004		
AVERAGE CHANGE	0.000+000	-3.000-006		
STD OF MEAN	0.000+000	5.000-006		
AVE PER CENT CHANGE	0.000+000	-2.606+000		
INTERVAL ESTIMATE	0.000+000	-6.153+000		
AS PER CENT	0.000+000	1.836+000		
PER CENT AVE CHANGE	0.000+000	-2.158+000		
F-TEST	5.349+001	2.860+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	1.092+000	-5.130-001	0.000+000	0.000+000
GROUPS P-S	2.992+000	1.814+000	0.000+000	0.000+000
GROUPS P-C	1.153+001	-9.068-001		
GROUPS D-S	1.729+000	2.223+000		
GROUPS D-C	9.783+000	-3.420-001		
GROUPS S-C	8.542+000	-2.721+000		

CODE WS113Q

	UNITS	V OUT 1-4 VOLTS	V OUT 0-7 VOLTS	V OUT 1-7 VOLTS	V OUT 0-4 VOLTS
GROUP P					
NUMBER		5	5	5	5
INITIAL MEAN		3.055+000	1.980-002	3.040+000	1.440-002
AVERAGE CHANGE		-2.290-001	6.620-002	-2.230-001	6.660-002
STD OF MEAN		3.442-002	1.467-002	2.324-002	8.718-003
AVE PER CENT CHANGE		-7.495+000	5.318+002	-7.334+000	6.130+002
INTERVAL ESTIMATE		-8.746+000	2.521+002	-8.183+000	3.953+002
AS PER CENT		-6.244+000	4.166+002	-6.486+000	5.297+002
PER CENT AVE CHANGE		-7.495+000	3.343+002	-7.335+000	4.625+002
GROUP D					
NUMBER		4	4	4	4
INITIAL MEAN		3.025+000	1.080-002	3.022+000	7.400-003
AVERAGE CHANGE		-1.583+000	8.975-002	-2.550-001	5.400-002
STD OF MEAN		1.773+000	6.762-002	2.797-002	1.379-002
AVE PER CENT CHANGE		-5.279+001	1.128+003	-8.455+000	9.817+002
INTERVAL ESTIMATE		-1.331+002	-3.170+001	-9.713+000	4.729+002
AS PER CENT		2.842+001	1.694+003	-7.163+000	9.865+002
PER CENT AVE CHANGE		-5.233+001	8.310+002	-8.438+000	7.297+002
GROUP S					
NUMBER		5	5	5	5
INITIAL MEAN		3.050+000	7.200-003	3.031+000	6.800-003
AVERAGE CHANGE		-7.518-001	6.580-002	-1.930-001	5.980-002
STD OF MEAN		1.391+000	2.125-002	5.079-002	5.557-003
AVE PER CENT CHANGE		-2.464+001	9.566+002	-6.369+000	1.021+003
INTERVAL ESTIMATE		-7.530+001	5.862+002	-8.229+000	7.887+002
AS PER CENT		2.600+001	1.242+003	-4.507+000	9.701+002
PER CENT AVE CHANGE		-2.465+001	9.139+002	-6.368+000	8.794+002
GROUP C					
NUMBER		5	5	5	5
INITIAL MEAN		3.019+000	1.480-002	3.009+000	1.160-002
AVERAGE CHANGE		-1.255+000	4.200-003	-9.980-002	5.200-003
STD OF MEAN		1.764+000	3.202-003	2.255-002	1.837-003
AVE PER CENT CHANGE		-4.186+001	4.560+001	-3.317+000	6.889+001
INTERVAL ESTIMATE		-1.065+002	4.358+000	-4.149+000	2.724+001
AS PER CENT		2.332+001	5.240+001	-2.485+000	6.241+001
PER CENT AVE CHANGE		-4.157+001	2.838+001	-3.317+000	4.483+001
F-TEST		1.044+000	7.604+000	2.358+001	7.462+001
T-TEST					
GROUPS P-D		1.622+000	-1.218+000	1.598+000	2.603+000
GROUPS P-S		6.642-001	2.195-002	-1.589+000	1.490+000
GROUPS P-C		1.304+000	3.402+000	-6.525+000	1.346+001
GROUPS D-S		-9.957-001	1.239+000	-3.096+000	-1.198+000
GROUPS D-C		-3.929-001	4.426+000	-7.749+000	1.008+001
GROUPS S-C		6.393-001	3.380+000	-4.936+000	1.197+001

CODE WS113Q

	IOUT-DRIVE	VOUT		
UNITS	MA	VOLTS		
GROUP P				
NUMBER	10	10		
INITIAL MEAN	3.380-001	2.701+000		
AVERAGE CHANGE	-2.103-001	-1.938-001		
STD OF MEAN	3.832-002	3.114-002		
AVE PER CENT CHANGE	-6.203+001	-7.168+000		
INTERVAL ESTIMATE	-6.991+001	-7.957+000		
AS PER CENT	-5.452+001	-6.393+000		
PER CENT AVE CHANGE	-6.222+001	-7.175+000		
GROUP D				
NUMBER	7	7		
INITIAL MEAN	2.854-001	2.669+000		
AVERAGE CHANGE	-1.854-001	-1.497-001		
STD OF MEAN	3.450-002	5.011-002		
AVE PER CENT CHANGE	-7.051+001	-5.625+000		
INTERVAL ESTIMATE	-7.531+001	-7.216+000		
AS PER CENT	-5.461+001	-4.001+000		
PER CENT AVE CHANGE	-6.496+001	-5.609+000		
GROUP S				
NUMBER	10	10		
INITIAL MEAN	2.275-001	2.591+000		
AVERAGE CHANGE	-9.020-002	-6.560-002		
STD OF MEAN	5.563-002	7.041-002		
AVE PER CENT CHANGE	-4.185+001	-2.486+000		
INTERVAL ESTIMATE	-5.624+001	-4.376+000		
AS PER CENT	-2.306+001	-6.878-001		
PER CENT AVE CHANGE	-3.965+001	-2.532+000		
GROUP C				
NUMBER	8	8		
INITIAL MEAN	2.685-001	2.624+000		
AVERAGE CHANGE	-8.187-002	-1.241-001		
STD OF MEAN	8.611-002	1.102-001		
AVE PER CENT CHANGE	-1.866+001	-4.603+000		
INTERVAL ESTIMATE	-5.558+001	-8.014+000		
AS PER CENT	-5.409+000	-1.446+000		
PER CENT AVE CHANGE	-3.049+001	-4.730+000		
F-TEST	1.350+001	6.491+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	-9.446-001	-1.354+000	0.000+000	0.000+000
GROUPS P-S	-5.026+000	-4.340+000	0.000+000	0.000+000
GROUPS P-C	-5.067+000	-2.224+000		
GROUPS D-S	-3.617+000	-2.584+000		
GROUPS D-C	-3.745+000	-7.485-001		
GROUPS S-C	-3.285-001	1.868+000		

CODE WS113Q

	T RISE	T FALL		
UNITS	NS	NS		
GROUP P				
NUMBER	10	10		
INITIAL MEAN	1.360+001	3.415+001		
AVERAGE CHANGE	6.000-001	6.415+001		
STD OF MEAN	9.192+000	8.759+001		
AVE PER CENT CHANGE	3.730+001	1.880+002		
INTERVAL ESTIMATE	-4.145+001	1.380+001		
AS PER CENT	5.028+001	3.619+002		
PER CENT AVE CHANGE	4.412+000	1.878+002		
GROUP D				
NUMBER	3	3		
INITIAL MEAN	1.615+001	9.860+001		
AVERAGE CHANGE	-1.667-001	3.300+001		
STD OF MEAN	6.195+000	1.738+002		
AVE PER CENT CHANGE	8.118+000	1.471+002		
INTERVAL ESTIMATE	-7.884+001	-3.241+002		
AS PER CENT	7.677+001	3.910+002		
PER CENT AVE CHANGE	-1.032+000	3.347+001		
GROUP S				
NUMBER	6	6		
INITIAL MEAN	1.030+001	4.680+001		
AVERAGE CHANGE	2.500+000	8.550+001		
STD OF MEAN	2.661+000	1.086+002		
AVE PER CENT CHANGE	2.610+001	2.036+002		
INTERVAL ESTIMATE	-4.804-001	-3.957+001		
AS PER CENT	4.902+001	4.050+002		
PER CENT AVE CHANGE	2.427+001	1.827+002		
GROUP C				
NUMBER	2	2		
INITIAL MEAN	8.750+000	3.787+001		
AVERAGE CHANGE	0.000+000	-2.000+000		
STD OF MEAN	0.000+000	0.000+000		
AVE PER CENT CHANGE	0.000+000	-4.651+000		
INTERVAL ESTIMATE	0.000+000	-5.281+000		
AS PER CENT	0.000+000	-5.281+000		
PER CENT AVE CHANGE	0.000+000	-5.281+000		
F-TEST	1.568-001	5.215-001	0.000+000	0.000+000
T-TEST				
GROUPS P-D	1.736-001	5.012-001	0.000+000	0.000+000
GROUPS P-S	-5.485-001	-4.379-001	0.000+000	0.000+000
GROUPS P-C	1.155-001	9.046-001		
GROUPS D-S	-5.622-001	-7.864-001		
GROUPS D-C	-2.722-002	4.061-001		
GROUPS S-C	4.564-001	1.135+000		

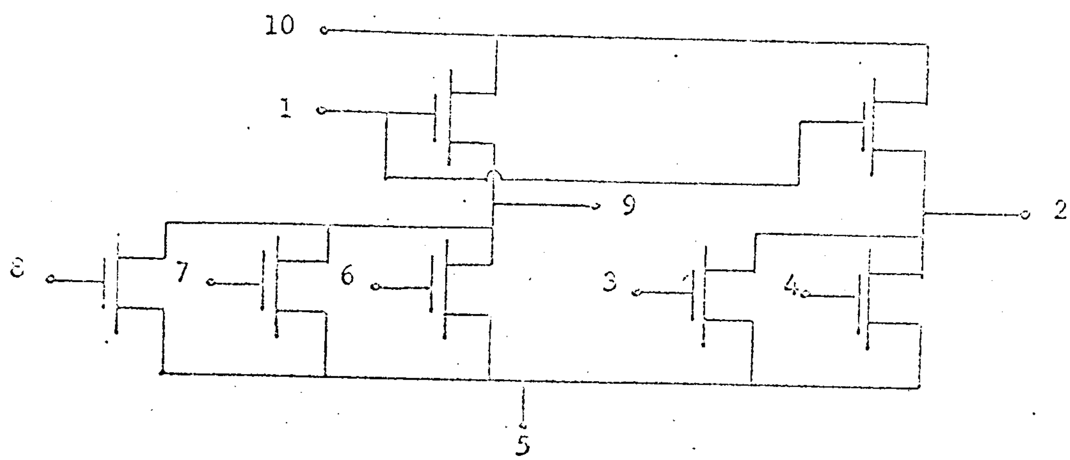
CODE WS113Q

	T DELAY	T STORE		
UNITS	NS	NS		
GROUP P				
NUMBER	10	10		
INITIAL MEAN	4.720+001	2.990+001		
AVERAGE CHANGE	2.000-001	-5.000-001		
STD OF MEAN	3.678+000	3.153+000		
AVE PER CENT CHANGE	5.520-001	-1.144+000		
INTERVAL ESTIMATE	-4.865+000	-8.827+000		
AS PER CENT	5.712+000	5.483+000		
PER CENT AVE CHANGE	4.237-001	-1.672+000		
GROUP D				
NUMBER	3	3		
INITIAL MEAN	7.170+001	3.940+001		
AVERAGE CHANGE	-1.867+001	-6.000+000		
STD OF MEAN	3.962+001	8.485+000		
AVE PER CENT CHANGE	-1.831+001	-1.489+001		
INTERVAL ESTIMATE	-1.381+002	-5.891+001		
AS PER CENT	8.605+001	2.846+001		
PER CENT AVE CHANGE	-2.603+001	-1.523+001		
GROUP S				
NUMBER	6	6		
INITIAL MEAN	5.990+001	3.550+001		
AVERAGE CHANGE	-4.000+000	-3.667+000		
STD OF MEAN	1.064+001	2.653+000		
AVE PER CENT CHANGE	-4.937+000	-9.506+000		
INTERVAL ESTIMATE	-2.370+001	-1.749+001		
AS PER CENT	1.035+001	-3.167+000		
PER CENT AVE CHANGE	-6.678+000	-1.033+001		
GROUP C				
NUMBER	2	2		
INITIAL MEAN	4.625+001	3.275+001		
AVERAGE CHANGE	6.500+000	0.000+000		
STD OF MEAN	1.700+001	2.000+000		
AVE PER CENT CHANGE	1.690+001	4.202-002		
INTERVAL ESTIMATE	-2.195+002	-3.880+001		
AS PER CENT	2.476+002	3.880+001		
PER CENT AVE CHANGE	1.405+001	0.000+000		
F-TEST	2.061+000	2.583+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	2.226+000	2.390+000	0.000+000	0.000+000
GROUPS P-S	6.316-001	1.754+000	0.000+000	0.000+000
GROUPS P-C	-6.316-001	-1.846-001		
GROUPS D-S	-1.611+000	-9.438-001		
GROUPS D-C	-2.141+000	-1.880+000		
GROUPS S-C	-9.987-001	-1.284+000		

TEST RESULT SUMMARY SHEET

Circuit Identification Code: General Instrument 7532

Circuit Diagram:



Circuit Description:

Function: NOR Gate
Process: MOS Technology
Advertised Speed: Not Listed

TEST RESULT SUMMARY SHEET (Continued) Code 7532

IN SITE DATA

Electron Fluence:
- To First Failure $< 2.5 \times 10^{12}$ e/cm^2
- Test Total 5×10^{12} e/cm^2

Failure Mode: V_{zero} exceeded -4 volts and V_{one} became less negative than -9 volts.

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	72 F	74 F	72 F	
V_{zero}*	Mean Value Volts	2.2	----	4.7	4.0
	Percent Change in Mean Value (%)	----	----	113.6	81.8
	Spread min./max.	2.0/2.6	----	3.2/6.6	2.8/5.6
V_{one}*	Mean Value Volts	10.7	----	8.1	6.6
	Percent Change in Mean Value (%)	----	----	-24.2	-38.3
	Spread min./max.	10.1/11.3	----	6.5/9.0	5.3/7.4
Pulsed Circuits	Temperature	72 F	74 F	72 F	
V_{one} Static Mode	Mean Value (Volts)	9.6	----	9.9*	9.4*
	Percent Change in Mean Value (%)	----	----	3.1	-2.1
	Spread min./max.	9.4/9.8	----	9.5/10.1	8.9/1.6
V_{one} Pulsed Mode	Mean Value (Volts)	9.1	8.2	----	9.6
	Percent Change in Mean Value (%)	----	- 9.9	----	5.5
	Spread min./max.	9.4/9.8	7.1/8.9	----	9.3/10.2
Dynamic Circuits	Temperature	72 F	75 F	72 F	
Multistage Propagation Delay	Mean Value (f^{-1} ns)	200	----	----	8500**
	Percent Change in Mean Value (%)	----	----	----	4150

*Final data was not plotted because monitor sampling time for five circuits = 20% of total fluence.

**Stopped oscillating between 1.0 and 1.2×10^{12} e/cm^2. Began oscillating once loads were removed.

CODE 7532

	UNITS	GM-2 MICROMHO	GM MICROMHO		
GROUP P					
NUMBER		5	10		
INITIAL MEAN		1.078+002	6.867+002		
AVERAGE CHANGE		-9.400+000	3.110+001		
STD OF MEAN		1.623+001	2.184+002		
AVE PER CENT CHANGE		-8.634+000	2.461+001		
INTERVAL ESTIMATE		-2.544+001	-1.705+001		
AS PER CENT		8.001+000	2.611+001		
PER CENT AVE CHANGE		-8.720+000	4.529+000		
GROUP D					
NUMBER		0	10		
INITIAL MEAN		1.120+002	6.921+002		
AVERAGE CHANGE		0.000+000	-1.138+002		
STD OF MEAN		-0.000+000	1.163+002		
AVE PER CENT CHANGE		0.000+000	-1.586+001		
INTERVAL ESTIMATE		0.000+000	-2.785+001		
AS PER CENT		0.000+000	-5.036+000		
PER CENT AVE CHANGE		0.000+000	-1.644+001		
GROUP S					
NUMBER		0	10		
INITIAL MEAN		1.012+002	6.106+002		
AVERAGE CHANGE		0.000+000	-4.090+001		
STD OF MEAN		-0.000+000	2.175+002		
AVE PER CENT CHANGE		0.000+000	6.205+000		
INTERVAL ESTIMATE		0.000+000	-3.087+001		
AS PER CENT		0.000+000	1.747+001		
PER CENT AVE CHANGE		0.000+000	-6.698+000		
GROUP C					
NUMBER		5	10		
INITIAL MEAN		1.046+002	6.889+002		
AVERAGE CHANGE		-3.000+000	1.450+002		
STD OF MEAN		1.075+001	1.247+002		
AVE PER CENT CHANGE		-3.007+000	2.873+001		
INTERVAL ESTIMATE		-1.428+001	8.769+000		
AS PER CENT		8.547+000	3.333+001		
PER CENT AVE CHANGE		-2.868+000	2.105+001		
F-TEST		1.688-001	4.359+000	0.000+000	0.000+000
T-TEST					
GROUPS P-D		-1.478+000	1.939+000	0.000+000	0.000+000
GROUPS P-S		-1.478+000	9.636-001	0.000+000	0.000+000
GROUPS P-C		-7.116-001	-1.524+000		
GROUPS D-S		0.000+000	-9.757-001		
GROUPS D-C		4.718-001	-3.464+000		
GROUPS S-C		4.718-001	-2.488+000		

CODE 7532

		ISDS-2	ISDS		
UNITS		MA	MA		
GROUP P					
NUMBER		5	10		
INITIAL MEAN		4.666-001	2.900+000		
AVERAGE CHANGE		-8.020-002	-8.334-001		
STD OF MEAN		1.001-001	3.677-001		
AVE PER CENT CHANGE		-1.700+001	-2.833+001		
INTERVAL ESTIMATE		-4.101+001	-3.734+001		
AS PER CENT		6.634+000	-2.013+001		
PER CENT AVE CHANGE		-1.719+001	-2.873+001		
GROUP D					
NUMBER		0	10		
INITIAL MEAN		5.266-001	2.678+000		
AVERAGE CHANGE		0.000+000	-1.442+000		
STD OF MEAN		-0.000+000	6.241-001		
AVE PER CENT CHANGE		0.000+000	-5.427+001		
INTERVAL ESTIMATE		0.000+000	-6.967+001		
AS PER CENT		0.000+000	-3.804+001		
PER CENT AVE CHANGE		0.000+000	-5.385+001		
GROUP S					
NUMBER		0	10		
INITIAL MEAN		4.790-001	2.589+000		
AVERAGE CHANGE		0.000+000	-1.160+000		
STD OF MEAN		-0.000+000	8.319-001		
AVE PER CENT CHANGE		0.000+000	-4.328+001		
INTERVAL ESTIMATE		0.000+000	-6.663+001		
AS PER CENT		0.000+000	-2.302+001		
PER CENT AVE CHANGE		0.000+000	-4.483+001		
GROUP C					
NUMBER		5	10		
INITIAL MEAN		4.946+000	2.744+000		
AVERAGE CHANGE		3.742-001	9.263-001		
STD OF MEAN		5.725-001	3.812-001		
AVE PER CENT CHANGE		3.573+000	3.493+001		
INTERVAL ESTIMATE		-5.287+000	2.433+001		
AS PER CENT		2.042+001	4.318+001		
PER CENT AVE CHANGE		7.565+000	3.376+001		
F-TEST		9.552-001	3.703+001	0.000+000	0.000+000
T-TEST					
GROUPS P-D		-4.225-001	2.458+000	0.000+000	0.000+000
GROUPS P-S		-4.225-001	1.321+000	0.000+000	0.000+000
GROUPS P-C		-1.693+000	-7.108+000		
GROUPS D-S		0.000+000	-1.137+000		
GROUPS D-C		-1.971+000	-9.566+000		
GROUPS S-C		-1.971+000	-8.429+000		

CODE 7532

	RDS-2	RDS		
UNITS	K OHMS	K OHMS		
GROUP P				
NUMBER	4	10		
INITIAL MEAN	4.206+001	1.212+001		
AVERAGE CHANGE	5.082+001	-9.320-001		
STD OF MEAN	8.821+001	6.610+000		
AVE PER CENT CHANGE	1.312+002	6.748+000		
INTERVAL ESTIMATE	-1.682+002	-4.470+001		
AS PER CENT	4.098+002	2.932+001		
PER CENT AVE CHANGE	1.208+002	-7.690+000		
GROUP D				
NUMBER	1	10		
INITIAL MEAN	1.096+002	1.532+001		
AVERAGE CHANGE	1.140+002	4.794+000		
STD OF MEAN	0.000+000	1.964+001		
AVE PER CENT CHANGE	1.030+002	4.186+001		
INTERVAL ESTIMATE	1.040+002	-5.571+001		
AS PER CENT	1.040+002	1.183+002		
PER CENT AVE CHANGE	1.040+002	3.129+001		
GROUP S				
NUMBER	0	10		
INITIAL MEAN	5.867+001	1.153+001		
AVERAGE CHANGE	0.000+000	5.428+000		
STD OF MEAN	-0.000+000	1.649+001		
AVE PER CENT CHANGE	0.000+000	9.564+001		
INTERVAL ESTIMATE	0.000+000	-4.998+001		
AS PER CENT	0.000+000	1.441+002		
PER CENT AVE CHANGE	0.000+000	4.706+001		
GROUP C				
NUMBER	5	10		
INITIAL MEAN	5.502+001	1.186+001		
AVERAGE CHANGE	1.198+001	1.499+001		
STD OF MEAN	2.985+001	5.579+001		
AVE PER CENT CHANGE	6.372+001	7.802+001		
INTERVAL ESTIMATE	-3.846+001	-1.929+002		
AS PER CENT	8.202+001	4.456+002		
PER CENT AVE CHANGE	2.178+001	1.264+002		
F-TEST	9.644-001	5.072-001	0.000+000	0.000+000
T-TEST				
GROUPS P-D	-9.701-001	-4.370-001	0.000+000	0.000+000
GROUPS P-S	1.745+000	-4.854-001	0.000+000	0.000+000
GROUPS P-C	9.940-001	-1.215+000		
GROUPS D-S	1.957+000	-4.839-002		
GROUPS D-C	1.599+000	-7.781-001		
GROUPS S-C	-4.599-001	-7.297-001		

CODE 7532

	VMX ZERO	VMIN ONE		
UNITS	NEGVOLTS	NEGVOLTS		
GROUP P				
NUMBER	10	10		
INITIAL MEAN	4.777+000	7.441+000		
AVERAGE CHANGE	2.255+000	1.853+000		
STD OF MEAN	3.746-001	4.940-001		
AVE PER CENT CHANGE	4.870+001	2.530+001		
INTERVAL ESTIMATE	4.169+001	2.039+001		
AS PER CENT	5.253+001	2.940+001		
PER CENT AVE CHANGE	4.721+001	2.490+001		
GROUP D				
NUMBER	7	10		
INITIAL MEAN	5.752+000	7.576+000		
AVERAGE CHANGE	-1.839-001	5.449-001		
STD OF MEAN	2.751+000	1.243+000		
AVE PER CENT CHANGE	4.544+000	7.240+000		
INTERVAL ESTIMATE	-4.415+001	-3.940+000		
AS PER CENT	3.775+001	1.832+001		
PER CENT AVE CHANGE	-3.196+000	7.192+000		
GROUP S				
NUMBER	9	10		
INITIAL MEAN	5.267+000	7.510+000		
AVERAGE CHANGE	9.097-001	7.049-001		
STD OF MEAN	2.463+000	1.758+000		
AVE PER CENT CHANGE	2.438+001	1.064+001		
INTERVAL ESTIMATE	-1.669+001	-6.500+000		
AS PER CENT	5.143+001	2.527+001		
PER CENT AVE CHANGE	1.727+001	9.387+000		
GROUP C				
NUMBER	10	10		
INITIAL MEAN	5.378+000	7.379+000		
AVERAGE CHANGE	-1.871-001	-4.140-002		
STD OF MEAN	1.145+000	3.277-002		
AVE PER CENT CHANGE	-5.102-001	-5.537-001		
INTERVAL ESTIMATE	-1.793+001	-8.624-001		
AS PER CENT	1.097+001	-2.597-001		
PER CENT AVE CHANGE	-3.479+000	-5.610-001		
F-TEST	4.261+000	5.723+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	2.850+000	2.791+000	0.000+000	0.000+000
GROUPS P-S	1.704+000	2.449+000	0.000+000	0.000+000
GROUPS P-C	3.177+000	4.042+000		
GROUPS D-S	-1.263+000	-3.414-001		
GROUPS D-C	3.829-003	1.251+000		
GROUPS S-C	1.369+000	1.592+000		

CODE 7532

	VMIN ONE-7	VMX ZERO-7		
UNITS	NEGVOLTS	NEGVOLTS		
GROUP P				
NUMBER	5	5		
INITIAL MEAN	6.828+000	5.006+000		
AVERAGE CHANGE	2.015+000	1.351+000		
STD OF MEAN	2.906-001	3.007-001		
AVE PER CENT CHANGE	2.969+001	2.730+001		
INTERVAL ESTIMATE	2.479+001	2.032+001		
AS PER CENT	3.424+001	3.366+001		
PER CENT AVE CHANGE	2.951+001	2.699+001		
GROUP D				
NUMBER	5	0		
INITIAL MEAN	7.359+000	5.411+000		
AVERAGE CHANGE	1.463+000	0.000+000		
STD OF MEAN	4.648-001	-0.000+000		
AVE PER CENT CHANGE	1.986+001	0.000+000		
INTERVAL ESTIMATE	1.287+001	0.000+000		
AS PER CENT	2.690+001	0.000+000		
PER CENT AVE CHANGE	1.988+001	0.000+000		
GROUP S				
NUMBER	5	0		
INITIAL MEAN	6.847+000	5.069+000		
AVERAGE CHANGE	2.095+000	0.000+000		
STD OF MEAN	2.953-001	-0.000+000		
AVE PER CENT CHANGE	3.070+001	0.000+000		
INTERVAL ESTIMATE	2.582+001	0.000+000		
AS PER CENT	3.539+001	0.000+000		
PER CENT AVE CHANGE	3.060+001	0.000+000		
GROUP C				
NUMBER	5	5		
INITIAL MEAN	7.100+000	5.294+000		
AVERAGE CHANGE	-2.200-003	-6.606-001		
STD OF MEAN	4.062-003	1.631-001		
AVE PER CENT CHANGE	-3.020-002	-1.242+001		
INTERVAL ESTIMATE	-9.451-002	-1.590+001		
AS PER CENT	3.254-002	-9.057+000		
PER CENT AVE CHANGE	-3.099-002	-1.248+001		
F-TEST	6.037+001	5.403+001	0.000+000	0.000+000
T-TEST				
GROUPS P-D	3.133+000	1.209+001	0.000+000	0.000+000
GROUPS P-S	-4.554-001	1.209+001	0.000+000	0.000+000
GROUPS P-C	1.145+001	1.273+001		
GROUPS D-S	-3.588+000	0.000+000		
GROUPS D-C	8.322+000	5.912+000		
GROUPS S-C	1.191+001	5.912+000		

CODE 7532

	V OUT 0-A1	V OUT 0-B1		
UNITS	NEGVOLTS	NEGVOLTS		
GROUP P				
NUMBER	5	5		
INITIAL MEAN	3.339+000	3.887+000		
AVERAGE CHANGE	4.608-001	2.380-002		
STD OF MEAN	3.287-001	1.760+000		
AVE PER CENT CHANGE	1.385+001	9.356-001		
INTERVAL ESTIMATE	2.868+000	-4.968+001		
AS PER CENT	2.473+001	5.090+001		
PER CENT AVE CHANGE	1.380+001	6.124-001		
GROUP D				
NUMBER	5	5		
INITIAL MEAN	3.576+000	3.808+000		
AVERAGE CHANGE	7.660-002	-2.333+000		
STD OF MEAN	1.167+000	2.827-001		
AVE PER CENT CHANGE	3.198+000	-6.120+001		
INTERVAL ESTIMATE	-3.409+001	-6.951+001		
AS PER CENT	3.837+001	-5.302+001		
PER CENT AVE CHANGE	2.142+000	-6.126+001		
GROUP S				
NUMBER	5	5		
INITIAL MEAN	3.330+000	4.231+000		
AVERAGE CHANGE	5.914-001	-2.542+000		
STD OF MEAN	1.047+000	9.193-001		
AVE PER CENT CHANGE	1.770+001	-5.922+001		
INTERVAL ESTIMATE	-1.716+001	-8.420+001		
AS PER CENT	5.269+001	-3.595+001		
PER CENT AVE CHANGE	1.776+001	-6.008+001		
GROUP C				
NUMBER	5	5		
INITIAL MEAN	3.355+000	3.761+000		
AVERAGE CHANGE	-1.083+000	-9.776-001		
STD OF MEAN	5.155-002	9.787-002		
AVE PER CENT CHANGE	-3.231+001	-2.602+001		
INTERVAL ESTIMATE	-3.398+001	-2.888+001		
AS PER CENT	-3.056+001	-2.310+001		
PER CENT AVE CHANGE	-3.227+001	-2.599+001		
F-TEST	5.643+000	9.025+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	8.475-001	4.150+000	0.000+000	0.000+000
GROUPS P-S	-2.881-001	4.517+000	0.000+000	0.000+000
GROUPS P-C	3.405+000	1.763+000		
GROUPS D-S	-1.136+000	3.676-001		
GROUPS D-C	2.557+000	-2.387+000		
GROUPS S-C	3.693+000	-2.754+000		

CODE 7532

	V OUT 1-A1	V OUT 1-B1	I DRIVE	
UNITS	NEGVOLTS	NEGVOLTS	AMPS	
GROUP P				
NUMBER	5	5	5	
INITIAL MEAN	1.009+001	1.004+001	3.852-004	
AVERAGE CHANGE	8.040-002	1.108-001	-7.600-006	
STD OF MEAN	2.941-001	7.248-001	4.845-005	
AVE PER CENT CHANGE	8.038-001	1.471+000	-1.978+000	
INTERVAL ESTIMATE	-2.441+000	-6.909+000	-1.594+001	
AS PER CENT	4.035+000	9.116+000	1.199+001	
PER CENT AVE CHANGE	7.970-001	1.103+000	-1.973+000	
GROUP D				
NUMBER	5	5	1	
INITIAL MEAN	1.021+001	1.014+001	3.990-004	
AVERAGE CHANGE	-4.448+000	-4.380+000	-3.460-004	
STD OF MEAN	7.375-001	7.531-001	0.000+000	
AVE PER CENT CHANGE	-4.354+001	-4.315+001	-9.611+001	
INTERVAL ESTIMATE	-5.160+001	-5.144+001	-8.672+001	
AS PER CENT	-3.555+001	-3.495+001	-8.672+001	
PER CENT AVE CHANGE	-4.358+001	-4.319+001	-8.672+001	
GROUP S				
NUMBER	5	5	4	
INITIAL MEAN	1.004+001	1.020+001	3.692-004	
AVERAGE CHANGE	-3.240+000	-3.359+000	-3.145-004	
STD OF MEAN	1.195+000	1.068+000	5.514-005	
AVE PER CENT CHANGE	-3.229+001	-3.299+001	-8.545+001	
INTERVAL ESTIMATE	-4.550+001	-4.457+001	-1.058+002	
AS PER CENT	-1.906+001	-2.131+001	-6.461+001	
PER CENT AVE CHANGE	-3.228+001	-3.294+001	-8.518+001	
GROUP C				
NUMBER	5	5	5	
INITIAL MEAN	1.017+001	1.010+001	3.874-004	
AVERAGE CHANGE	-3.244-001	-3.190-001	-4.740-005	
STD OF MEAN	1.287-001	1.636-001	2.504-005	
AVE PER CENT CHANGE	-3.190+000	-3.150+000	-1.215+001	
INTERVAL ESTIMATE	-4.594+000	-4.956+000	-1.941+001	
AS PER CENT	-1.765+000	-1.360+000	-5.057+000	
PER CENT AVE CHANGE	-3.189+000	-3.158+000	-1.224+001	
F-TEST	5.889+001	5.452+001	6.533+001	0.000+000
T-TEST				
GROUPS P-D	1.111+001	1.056+001	8.010+000	0.000+000
GROUPS P-S	8.149+000	8.159+000	1.186+001	0.000+000
GROUPS P-C	9.935-001	1.011+000	1.632+000	
GROUPS D-S	-2.965+000	-2.400+000	-7.305-001	
GROUPS D-C	-1.012+001	-9.549+000	-7.068+000	
GROUPS S-C	-7.156+000	-7.149+000	-1.032+001	

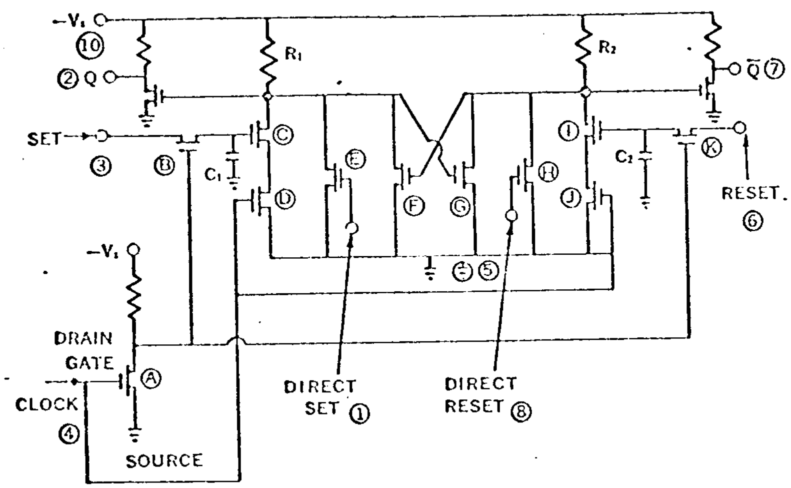
CODE 7532

	T STORE	T DELAY	T RISE	T FALL
UNITS	NS	NS	NS	NS
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	2.660+001	1.920+001	7.280+001	2.400+002
AVERAGE CHANGE	1.800+000	7.400+000	8.100+001	3.600+001
STD OF MEAN	6.490+000	1.696+000	2.025+001	2.417+001
AVE PER CENT CHANGE	6.691+000	3.921+001	1.115+002	1.520+001
INTERVAL ESTIMATE	-2.033+001	2.874+001	8.038+001	3.816+000
AS PER CENT	3.386+001	4.835+001	1.421+002	2.618+001
PER CENT AVE CHANGE	6.767+000	3.854+001	1.113+002	1.500+001
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	2.620+001	2.040+001	7.960+001	2.480+002
AVERAGE CHANGE	2.360+001	3.580+001	1.604+002	5.140+002
STD OF MEAN	7.649+000	1.966+001	1.033+001	1.085+002
AVE PER CENT CHANGE	9.092+001	1.764+002	2.020+002	2.087+002
INTERVAL ESTIMATE	5.766+001	6.848+001	1.871+002	1.587+002
AS PER CENT	1.225+002	2.825+002	2.159+002	2.558+002
PER CENT AVE CHANGE	9.008+001	1.755+002	2.015+002	2.073+002
GROUP S				
NUMBER	5	5	5	5
INITIAL MEAN	2.800+001	1.980+001	7.880+001	2.670+002
AVERAGE CHANGE	2.260+001	2.600+001	1.802+002	4.690+002
STD OF MEAN	1.371+001	4.743+000	2.232+001	7.031+001
AVE PER CENT CHANGE	8.334+001	1.332+002	2.367+002	1.785+002
INTERVAL ESTIMATE	2.636+001	1.047+002	1.972+002	1.464+002
AS PER CENT	1.351+002	1.579+002	2.601+002	2.049+002
PER CENT AVE CHANGE	8.071+001	1.313+002	2.287+002	1.757+002
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	2.520+001	1.840+001	7.360+001	2.400+002
AVERAGE CHANGE	2.000-001	-2.600+000	5.000+000	7.000+000
STD OF MEAN	5.000-001	2.031+000	3.708+000	1.346+001
AVE PER CENT CHANGE	8.000-001	-1.454+001	6.642+000	3.110+000
INTERVAL ESTIMATE	-1.410+000	-2.639+001	1.199+000	-3.312+000
AS PER CENT	2.997+000	-1.874+000	1.239+001	9.146+000
PER CENT AVE CHANGE	7.937-001	-1.413+001	6.793+000	2.917+000
F-TEST	1.415+001	1.823+001	1.563+002	1.060+002
T-TEST				
GROUPS P-D	-4.536+000	-4.923+000	-8.752+000	-1.278+001
GROUPS P-S	-4.328+000	-3.224+000	-1.093+001	-1.158+001
GROUPS P-C	3.329-001	1.733+000	8.377+000	7.755-001
GROUPS D-S	2.081-001	1.699+000	-2.183+000	1.203+000
GROUPS D-C	4.869+000	6.656+000	1.713+001	1.356+001
GROUPS S-C	4.661+000	4.958+000	1.931+001	1.235+001

TEST RESULT SUMMARY SHEET

Circuit Identification Code: General Instrument 7531(MEM529)

Circuit Diagram:



Circuit Description:

Function: R-S-T Flip Flop
Process: MOS Technology
Advertised Speed: Clock Frequency
1 mHz Maximum

TEST RESULT SUMMARY SHEET (Continued)

Code 7531

IN SITE DATA

Electron Fluence:
To First Failure $< 1.2 \times 10^{11}$ e/cm^2
Test Total 1×10^{12} e/cm^2

Failure Mode: V_{one} decreased to less than -10 volts

Monitored Parameters:		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	70 F	72 F	71 F	
V_{zero}	Mean Value (Volts)	< .1	< .1	< .1	< .1
V_{one}	Mean Value (Volts)	15.1	----	6.0	6.2
	Percent Change in Mean Value (%)	----	----	-60	-59
	Spread min./max.	14.7/15.7	----	4.8/7.3	5.1/7.4
Pulsed Circuits	Temperature	70 F	72 F	71 F	
V_{one} Static Mode	Mean Value	15.2	----	9.9*	9.9*
	Percent Change in Mean Value	----	----	-34.9	-34.9
	Spread min./max.	14.9/15.7	----	8.4/11.6	8.3/11.4
V_{zero} Pulse Mode					
	Too low to measure				
Dynamic Circuits	Temperature	70 F	72 F	71 F	
	Circuits failed almost immediately when they were placed in the radiation environment.				

*After 15 minutes continuous operation.

CODE 7531

VTH-8

UNITS NEGVOLTS

GROUP P

NUMBER	10
INITIAL MEAN	7.971+000
AVERAGE CHANGE	-3.830-001
STD OF MEAN	2.058-001
AVE PER CENT CHANGE	-4.730+000
INTERVAL ESTIMATE	-6.557+000
AS PER CENT	-3.053+000
PER CENT AVE CHANGE	-4.805+000

GROUP D

NUMBER	10
INITIAL MEAN	7.902+000
AVERAGE CHANGE	-1.768+000
STD OF MEAN	1.053+000
AVE PER CENT CHANGE	-2.232+001
INTERVAL ESTIMATE	-3.166+001
AS PER CENT	-1.358+001
PER CENT AVE CHANGE	-2.262+001

GROUP S

NUMBER	10
INITIAL MEAN	7.796+000
AVERAGE CHANGE	-1.961+000
STD OF MEAN	1.008+000
AVE PER CENT CHANGE	-2.503+001
INTERVAL ESTIMATE	-3.393+001
AS PER CENT	-1.637+001
PER CENT AVE CHANGE	-2.515+001

GROUP C

NUMBER	8
INITIAL MEAN	7.726+000
AVERAGE CHANGE	-4.250-003
STD OF MEAN	2.988-002
AVE PER CENT CHANGE	-6.034-002
INTERVAL ESTIMATE	-3.575-001
AS PER CENT	2.474-001
PER CENT AVE CHANGE	-5.501-002

F-TEST	1.734+001	0.000+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	4.370+000	0.000+000	0.000+000	0.000+000
GROUPS P-S	4.908+000	0.000+000	0.000+000	0.000+000
GROUPS P-C	-1.111+000			
GROUPS D-S	5.385-001			
GROUPS D-C	-5.231+000			
GROUPS S-C	-5.739+000			

CODE 7531

VTH-6

UNITS NEGVOLTS

GROUP P	
NUMBER	10
INITIAL MEAN	3.829+000
AVERAGE CHANGE	2.670+000
STD OF MEAN	2.847+000
AVE PER CENT CHANGE	5.927+002
INTERVAL ESTIMATE	1.928+001
AS PER CENT	1.202+002
PER CENT AVE CHANGE	6.974+001
GROUP D	
NUMBER	0
INITIAL MEAN	3.660+000
AVERAGE CHANGE	0.000+000
STD OF MEAN	-0.000+000
AVE PER CENT CHANGE	0.000+000
INTERVAL ESTIMATE	0.000+000
AS PER CENT	0.000+000
PER CENT AVE CHANGE	0.000+000
GROUP S	
NUMBER	2
INITIAL MEAN	3.632+000
AVERAGE CHANGE	-5.244+000
STD OF MEAN	5.820-001
AVE PER CENT CHANGE	-9.230+001
INTERVAL ESTIMATE	-2.462+002
AS PER CENT	-4.259+001
PER CENT AVE CHANGE	-1.444+002
GROUP C	
NUMBER	8
INITIAL MEAN	3.706+000
AVERAGE CHANGE	-8.667-001
STD OF MEAN	1.943+000
AVE PER CENT CHANGE	-1.279+001
INTERVAL ESTIMATE	-6.439+001
AS PER CENT	1.762+001
PER CENT AVE CHANGE	-2.339+001

F-TEST	7.675+000	0.000+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	3.581+000	0.000+000	0.000+000	0.000+000
GROUPS P-S	4.333+000	0.000+000	0.000+000	0.000+000
GROUPS P-C	3.163+000			
GROUPS D-S	3.145+000			
GROUPS D-C	1.040+000			
GROUPS S-C	-2.348+000			

CODE 7531

	TW	VA		
UNITS	NS	VOLTS		
GROUP P				
NUMBER	1	1		
INITIAL MEAN	1.400+002	8.060+000		
AVERAGE CHANGE	-1.500+001	1.000-001		
STD OF MEAN	0.000+000	0.000+000		
AVE PER CENT CHANGE	-7.143+000	1.316+000		
INTERVAL ESTIMATE	-1.071+001	1.241+000		
AS PER CENT	-1.071+001	1.241+000		
PER CENT AVE CHANGE	-1.071+001	1.241+000		
GROUP D				
NUMBER	0	0		
INITIAL MEAN	1.160+002	7.980+000		
AVERAGE CHANGE	0.000+000	0.000+000		
STD OF MEAN	-0.000+000	-0.000+000		
AVE PER CENT CHANGE	0.000+000	0.000+000		
INTERVAL ESTIMATE	0.000+000	0.000+000		
AS PER CENT	0.000+000	0.000+000		
PER CENT AVE CHANGE	0.000+000	0.000+000		
GROUP S				
NUMBER	0	0		
INITIAL MEAN	1.268+002	7.860+000		
AVERAGE CHANGE	0.000+000	0.000+000		
STD OF MEAN	-0.000+000	-0.000+000		
AVE PER CENT CHANGE	0.000+000	0.000+000		
INTERVAL ESTIMATE	0.000+000	0.000+000		
AS PER CENT	0.000+000	0.000+000		
PER CENT AVE CHANGE	0.000+000	0.000+000		
GROUP C				
NUMBER	4	4		
INITIAL MEAN	1.330+002	8.050+000		
AVERAGE CHANGE	-5.250+000	3.000-001		
STD OF MEAN	1.949+001	3.266-001		
AVE PER CENT CHANGE	-4.486+000	3.907+000		
INTERVAL ESTIMATE	-2.414+001	-1.863+000		
AS PER CENT	1.624+001	9.317+000		
PER CENT AVE CHANGE	-3.947+000	3.727+000		
F-TEST	2.966-002	4.444-002	0.000+000	0.000+000
T-TEST				
GROUPS P-D	-5.131-001	2.041-001	0.000+000	0.000+000
GROUPS P-S	-5.131-001	2.041-001	0.000+000	0.000+000
GROUPS P-C	-2.983-001	-3.651-001		
GROUPS D-S	0.000+000	0.000+000		
GROUPS D-C	3.591-001	-1.225+000		
GROUPS S-C	3.591-001	-1.225+000		

CODE 7531

	V OUT 1	V OUT-1- L		
UNITS	NEGVOLTS	NEGVOLTS		
GROUP P				
NUMBER	10	10		
INITIAL MEAN	1.530+001	1.330+001		
AVERAGE CHANGE	-3.481+000	-3.472+000		
STD OF MEAN	3.876-001	3.365-001		
AVE PER CENT CHANGE	-2.282+001	-2.623+001		
INTERVAL ESTIMATE	-2.446+001	-2.783+001		
AS PER CENT	-2.103+001	-2.440+001		
PER CENT AVE CHANGE	-2.274+001	-2.612+001		
GROUP D				
NUMBER	10	10		
INITIAL MEAN	1.580+001	1.382+001		
AVERAGE CHANGE	-8.462+000	-8.208+000		
STD OF MEAN	6.196-001	8.711-001		
AVE PER CENT CHANGE	-5.366+001	-5.943+001		
INTERVAL ESTIMATE	-5.622+001	-6.366+001		
AS PER CENT	-5.090+001	-5.510+001		
PER CENT AVE CHANGE	-5.356+001	-5.938+001		
GROUP S				
NUMBER	7	7		
INITIAL MEAN	1.503+001	1.416+001		
AVERAGE CHANGE	-7.720+000	-7.725+000		
STD OF MEAN	2.196+000	1.536+000		
AVE PER CENT CHANGE	-4.709+001	-5.430+001		
INTERVAL ESTIMATE	-6.390+001	-6.386+001		
AS PER CENT	-3.887+001	-4.527+001		
PER CENT AVE CHANGE	-5.138+001	-5.457+001		
GROUP C				
NUMBER	10	10		
INITIAL MEAN	1.337+001	1.174+001		
AVERAGE CHANGE	6.004-001	3.671-001		
STD OF MEAN	5.199-001	4.441-001		
AVE PER CENT CHANGE	3.196+000	3.205+000		
INTERVAL ESTIMATE	1.852+000	5.596-001		
AS PER CENT	7.129+000	5.693+000		
PER CENT AVE CHANGE	4.490+000	3.126+000		
F-TEST	1.756+002	2.420+002	0.000+000	0.000+000
T-TEST				
GROUPS P-D	1.143+001	1.334+001	0.000+000	0.000+000
GROUPS P-S	8.830+000	1.087+001	0.000+000	0.000+000
GROUPS P-C	-9.367+000	-1.081+001		
GROUPS D-S	-1.545+000	-1.235+000		
GROUPS D-C	-2.080+001	-2.415+001		
GROUPS S-C	-1.733+001	-2.068+001		

CODE 7531

	T RISE	T FALL		
UNITS	NS	NS		
GROUP P				
NUMBER	2	2		
INITIAL MEAN	1.620+002	6.200+002		
AVERAGE CHANGE	2.250+001	3.250+002		
STD OF MEAN	2.500+001	7.000+001		
AVE PER CENT CHANGE	1.357+001	5.923+001		
INTERVAL ESTIMATE	-8.415+001	-1.931+001		
AS PER CENT	1.119+002	1.241+002		
PER CENT AVE CHANGE	1.389+001	5.242+001		
GROUP D				
NUMBER	0	0		
INITIAL MEAN	1.440+002	5.420+002		
AVERAGE CHANGE	0.000+000	0.000+000		
STD OF MEAN	-0.000+000	-0.000+000		
AVE PER CENT CHANGE	0.000+000	0.000+000		
INTERVAL ESTIMATE	0.000+000	0.000+000		
AS PER CENT	0.000+000	0.000+000		
PER CENT AVE CHANGE	0.000+000	0.000+000		
GROUP S				
NUMBER	0	0		
INITIAL MEAN	1.440+002	6.190+002		
AVERAGE CHANGE	0.000+000	0.000+000		
STD OF MEAN	-0.000+000	-0.000+000		
AVE PER CENT CHANGE	0.000+000	0.000+000		
INTERVAL ESTIMATE	0.000+000	0.000+000		
AS PER CENT	0.000+000	0.000+000		
PER CENT AVE CHANGE	0.000+000	0.000+000		
GROUP C				
NUMBER	8	8		
INITIAL MEAN	1.462+002	5.438+002		
AVERAGE CHANGE	1.875+000	1.137+002		
STD OF MEAN	1.141+001	6.879+001		
AVE PER CENT CHANGE	1.520+000	2.272+001		
INTERVAL ESTIMATE	-4.818+000	1.102+001		
AS PER CENT	7.382+000	3.082+001		
PER CENT AVE CHANGE	1.282+000	2.092+001		
F-TEST	1.227+000	4.543+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	2.340+000	6.350+000	0.000+000	0.000+000
GROUPS P-S	2.340+000	6.350+000	0.000+000	0.000+000
GROUPS P-C	1.919+000	3.692+000		
GROUPS D-S	0.000+000	0.000+000		
GROUPS D-C	-3.900-001	-4.445+000		
GROUPS S-C	-3.900-001	-4.445+000		

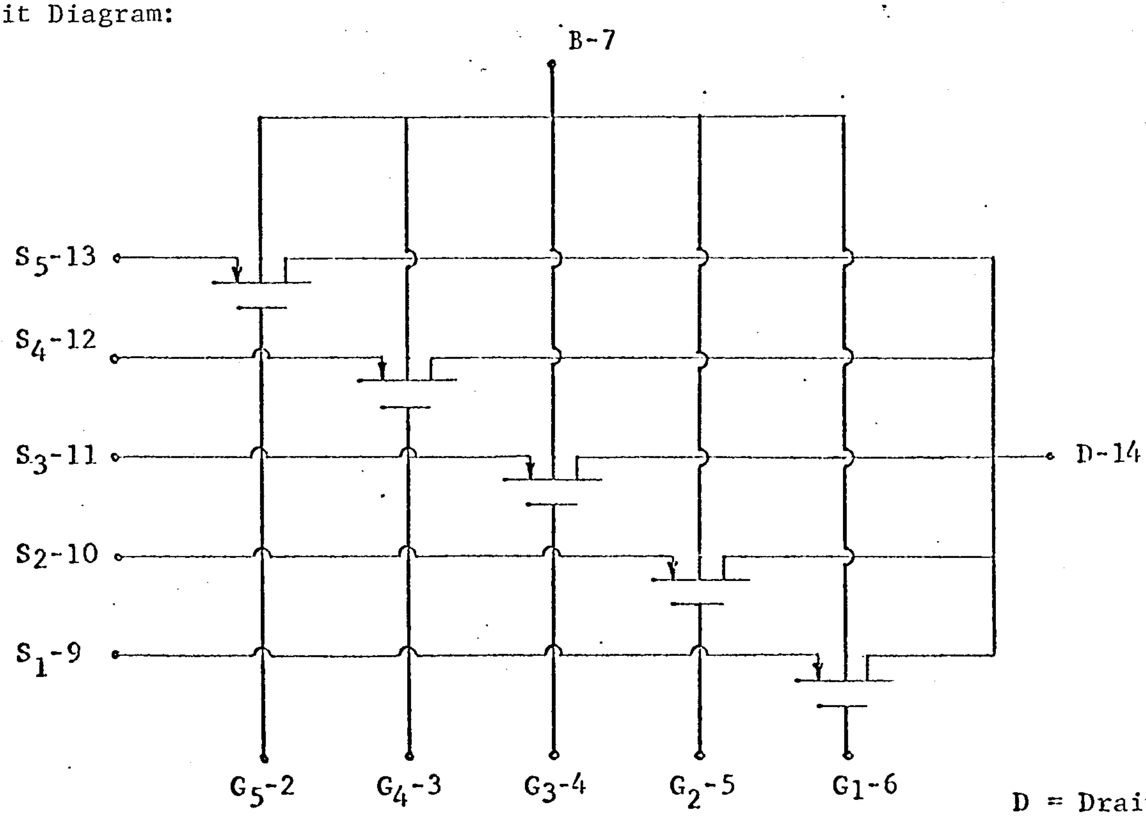
CODE 7531

	T DELAY	T STORE		
UNITS	NS	NS		
GROUP P				
NUMBER	2	2		
INITIAL MEAN	1.835+002	1.825+002		
AVERAGE CHANGE	8.500+001	1.025+002		
STD OF MEAN	1.000+001	1.500+001		
AVE PER CENT CHANGE	4.474+001	5.395+001		
INTERVAL ESTIMATE	1.170+001	3.948+000		
AS PER CENT	8.094+001	1.084+002		
PER CENT AVE CHANGE	4.632+001	5.616+001		
GROUP D				
NUMBER	0	0		
INITIAL MEAN	1.850+002	1.750+002		
AVERAGE CHANGE	0.000+000	0.000+000		
STD OF MEAN	-0.000+000	-0.000+000		
AVE PER CENT CHANGE	0.000+000	0.000+000		
INTERVAL ESTIMATE	0.000+000	0.000+000		
AS PER CENT	0.000+000	0.000+000		
PER CENT AVE CHANGE	0.000+000	0.000+000		
GROUP S				
NUMBER	0	0		
INITIAL MEAN	1.700+002	1.630+002		
AVERAGE CHANGE	0.000+000	0.000+000		
STD OF MEAN	-0.000+000	-0.000+000		
AVE PER CENT CHANGE	0.000+000	0.000+000		
INTERVAL ESTIMATE	0.000+000	0.000+000		
AS PER CENT	0.000+000	0.000+000		
PER CENT AVE CHANGE	0.000+000	0.000+000		
GROUP C				
NUMBER	8	8		
INITIAL MEAN	1.750+002	1.775+002		
AVERAGE CHANGE	-6.375+000	-9.625+000		
STD OF MEAN	2.074+001	2.543+001		
AVE PER CENT CHANGE	-3.538+000	-5.050+000		
INTERVAL ESTIMATE	-1.291+001	-1.663+001		
AS PER CENT	5.625+000	5.782+000		
PER CENT AVE CHANGE	-3.643+000	-5.423+000		
F-TEST	9.955+000	9.879+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	5.684+000	5.564+000	0.000+000	0.000+000
GROUPS P-S	5.684+000	5.564+000	0.000+000	0.000+000
GROUPS P-C	5.465+000	5.444+000		
GROUPS D-S	0.000+000	0.000+000		
GROUPS D-C	8.525-001	1.045+000		
GROUPS S-C	8.525-001	1.045+000		

TEST RESULT SUMMARY SHEET

Circuit Identification Code: Fairchild μM400

Circuit Diagram:



D = Drain
S = Source
G = Gate
B = Body (Substrate)

Circuit Description:

Function: 5 MOS P-Channel Transistor
Process: Planar II
Advertised Speed: Not Listed

TEST RESULT SUMMARY SHEET (Continued)

Code μM400

IN SITE DATA

Electron Fluence:
- To First Failure $< 1.2 \times 10^{11}$ e/cm^2
- Test Total 2.5×10^{11} e/cm^2

Failure Mode: V_{zero} become more negative that -4.0 volts

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	72 F	74 F	73 F	
V_{zero}	Mean Value (Volts)	1.8	----	5.5	5.1
	Percent Change in Mean Value (%)	----	----	205	183
	Spread min./max.	1.6/2.2	----	2.9/7.5	4.1/6.6
V_{one}	Mean Value (Volts)	11.4	----	11.3	10.6
	Percent Change in Mean Value (%)	----	----	-1	-7
	Spread min./max.	11.4/11.4	----	11.3/11.4	10.6/10.6
Pulsed Circuits	Temperature	72 F	74 F	73 F	
V_{zero} Static Mode	Mean Value (Volts)	3.1	----	4.5*	4.2*
	Percent Change in Mean Value (%)	----	----	48.3	35.5
	Spread min./max.	2.1/3.9	----	2.9/6.15	2.8/6.9
V_{zero} Pulsed Mode	Mean Value (Volts)	3.7	----	6.3	4.0
	Percent Change in Mean Value (%)	----	----	70.3	8.1
	Spread min./max.	2.3/5.7	----	4.6/8.6	2.6/6.8
Dynamic Circuits	Temperature	72 F	74 F	73 F	
Multistage Propagation Delay	Mean Value (f^{-1} ns)	1900	1900	----	----
	Percent Change in Mean Value (%)	----	0.0	----	----

*After 15 minutes continuous operation.

CODE μM400

	GM	RDS		
UNITS	MICROMHO	K OHMS		
GROUP P				
NUMBER	10	10		
INITIAL MEAN	5.176+002	1.884+002		
AVERAGE CHANGE	-6.070+001	7.707+001		
STD OF MEAN	2.661+001	5.597+001		
AVE PER CENT CHANGE	-1.137+001	4.786+001		
INTERVAL ESTIMATE	-1.522+001	2.075+001		
AS PER CENT	-8.239+000	6.108+001		
PER CENT AVE CHANGE	-1.173+001	4.092+001		
GROUP D				
NUMBER	10	8		
INITIAL MEAN	4.430+002	2.505+002		
AVERAGE CHANGE	-1.739+002	-6.146+001		
STD OF MEAN	1.298+002	1.715+002		
AVE PER CENT CHANGE	-3.836+001	9.266+000		
INTERVAL ESTIMATE	-5.913+001	-7.808+001		
AS PER CENT	-1.938+001	2.901+001		
PER CENT AVE CHANGE	-3.926+001	-2.454+001		
GROUP S				
NUMBER	10	10		
INITIAL MEAN	5.917+002	1.655+002		
AVERAGE CHANGE	-1.289+002	5.659+001		
STD OF MEAN	1.015+002	1.399+002		
AVE PER CENT CHANGE	-2.249+001	8.414+001		
INTERVAL ESTIMATE	-3.342+001	-2.319+001		
AS PER CENT	-1.014+001	9.157+001		
PER CENT AVE CHANGE	-2.178+001	3.419+001		
GROUP C				
NUMBER	10	10		
INITIAL MEAN	5.945+002	2.190+002		
AVERAGE CHANGE	-4.500+000	-4.652+001		
STD OF MEAN	2.627+001	1.016+002		
AVE PER CENT CHANGE	-8.219-001	-8.144+000		
INTERVAL ESTIMATE	-3.755+000	-5.272+001		
AS PER CENT	2.241+000	1.023+001		
PER CENT AVE CHANGE	-7.569-001	-2.125+001		
F-TEST	8.672+000	3.532+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	3.159+000	2.545+000	0.000+000	0.000+000
GROUPS P-S	1.903+000	3.991-001	0.000+000	0.000+000
GROUPS P-C	-1.568+000	2.408+000		
GROUPS D-S	-1.256+000	-2.169+000		
GROUPS D-C	-4.727+000	-2.745-001		
GROUPS S-C	-3.471+000	2.009+000		

CODE μM400

	IDSS	ISDS		
UNITS	AMPS	AMPS		
GROUP P				
NUMBER	5	9		
INITIAL MEAN	1.802-009	1.389-003		
AVERAGE CHANGE	7.565-009	-4.167-004		
STD OF MEAN	1.871-008	1.602-004		
AVE PER CENT CHANGE	1.237+002	-2.991+001		
INTERVAL ESTIMATE	-7.333+002	-3.836+001		
AS PER CENT	1.573+003	-2.164+001		
PER CENT AVE CHANGE	4.199+002	-3.000+001		
GROUP D				
NUMBER	5	7		
INITIAL MEAN	3.158-010	1.102-003		
AVERAGE CHANGE	7.720-009	-6.000-004		
STD OF MEAN	1.510-008	4.655-004		
AVE PER CENT CHANGE	2.824+003	-5.448+001		
INTERVAL ESTIMATE	-2.866+003	-9.062+001		
AS PER CENT	7.755+003	-1.828+001		
PER CENT AVE CHANGE	2.445+003	-5.445+001		
GROUP S				
NUMBER	5	10		
INITIAL MEAN	2.262-010	1.775-003		
AVERAGE CHANGE	2.732-007	-8.930-004		
STD OF MEAN	6.424-007	6.234-004		
AVE PER CENT CHANGE	5.721+005	-5.233+001		
INTERVAL ESTIMATE	-1.946+005	-7.414+001		
AS PER CENT	4.361+005	-2.648+001		
PER CENT AVE CHANGE	1.208+005	-5.031+001		
GROUP C				
NUMBER	5	10		
INITIAL MEAN	1.598-010	1.647-003		
AVERAGE CHANGE	6.560-011	-2.500-005		
STD OF MEAN	2.708-010	2.950-005		
AVE PER CENT CHANGE	2.443+001	-1.285+000		
INTERVAL ESTIMATE	-1.471+002	-2.733+000		
AS PER CENT	2.292+002	-3.024-001		
PER CENT AVE CHANGE	4.105+001	-1.518+000		
F-TEST	1.088+000	9.373+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	-8.557-004	9.753-001	0.000+000	0.000+000
GROUPS P-S	-1.461+000	2.779+000	0.000+000	0.000+000
GROUPS P-C	4.124-002	-2.285+000		
GROUPS D-S	-1.460+000	1.594+000		
GROUPS D-C	4.210-002	-3.128+000		
GROUPS S-C	1.502+000	-5.203+000		

CODE μM400

	VTH	BVDSS	BVSDS	
UNITS	VOLTS	NEGVOLTS	NEGVOLTS	
GROUP P				
NUMBER	10	5	5	
INITIAL MEAN	5.266+000	4.098+001	6.057+001	
AVERAGE CHANGE	8.136-001	6.876+000	-7.294+000	
STD OF MEAN	9.075-002	1.251+001	2.315+001	
AVE PER CENT CHANGE	1.570+001	8.977+001	-1.248+001	
INTERVAL ESTIMATE	1.428+001	-1.711+001	-5.448+001	
AS PER CENT	1.662+001	5.067+001	3.039+001	
PER CENT AVE CHANGE	1.545+001	1.678+001	-1.204+001	
GROUP D				
NUMBER	10	5	5	
INITIAL MEAN	5.254+000	4.593+001	6.021+001	
AVERAGE CHANGE	2.914+000	-3.112+000	2.224+000	
STD OF MEAN	2.173+000	1.295+001	3.445+000	
AVE PER CENT CHANGE	5.663+001	-7.374+000	4.323+000	
INTERVAL ESTIMATE	2.741+001	-3.808+001	-2.660+000	
AS PER CENT	8.353+001	2.453+001	1.005+001	
PER CENT AVE CHANGE	5.547+001	-6.776+000	3.694+000	
GROUP S				
NUMBER	10	5	5	
INITIAL MEAN	4.683+000	4.267+001	5.241+001	
AVERAGE CHANGE	1.824+000	1.518+000	1.522+000	
STD OF MEAN	9.980-001	2.558+000	2.136+000	
AVE PER CENT CHANGE	4.065+001	2.513+000	4.727+000	
INTERVAL ESTIMATE	2.448+001	-3.101+000	-1.621+000	
AS PER CENT	5.340+001	1.022+001	7.428+000	
PER CENT AVE CHANGE	3.894+001	3.557+000	2.904+000	
GROUP C				
NUMBER	10	5	5	
INITIAL MEAN	4.884+000	5.857+001	4.574+001	
AVERAGE CHANGE	8.000-004	1.346+000	2.344+000	
STD OF MEAN	1.039-002	2.178+000	1.673+000	
AVE PER CENT CHANGE	2.872-002	2.721+000	1.048+001	
INTERVAL ESTIMATE	-1.279-001	-1.832+000	1.064+000	
AS PER CENT	1.607-001	6.428+000	9.186+000	
PER CENT AVE CHANGE	1.638-002	2.298+000	5.125+000	
F-TEST	1.235+001	1.245+000	9.848-001	0.000+000
T-TEST				
GROUPS P-D	-4.139+000	1.928+000	-1.428+000	0.000+000
GROUPS P-S	-1.991+000	1.035+000	-1.323+000	0.000+000
GROUPS P-C	1.601+000	1.068+000	-1.446+000	
GROUPS D-S	2.148+000	-8.938-001	1.053-001	
GROUPS D-C	5.740+000	-8.606-001	-1.804-002	
GROUPS S-C	3.592+000	3.313-002	-1.234-001	

CODE μM400

I LEAK-G

UNITS AMPS

GROUP P

NUMBER	8
INITIAL MEAN	1.200-009
AVERAGE CHANGE	2.250-008
STD OF MEAN	6.803-008
AVE PER CENT CHANGE	4.592+006
INTERVAL ESTIMATE	-2.559+003
AS PER CENT	6.308+003
PER CENT AVE CHANGE	1.875+003

GROUP D

NUMBER	5
INITIAL MEAN	5.575-013
AVERAGE CHANGE	1.080-013
STD OF MEAN	1.831-012
AVE PER CENT CHANGE	1.350+002
INTERVAL ESTIMATE	-3.454+002
AS PER CENT	3.841+002
PER CENT AVE CHANGE	1.937+001

GROUP S

NUMBER	7
INITIAL MEAN	9.222-013
AVERAGE CHANGE	5.777-012
STD OF MEAN	1.060-011
AVE PER CENT CHANGE	1.951+002
INTERVAL ESTIMATE	-3.575+002
AS PER CENT	1.610+003
PER CENT AVE CHANGE	6.264+002

GROUP C

NUMBER	8
INITIAL MEAN	2.590-013
AVERAGE CHANGE	5.360-011
STD OF MEAN	1.626-010
AVE PER CENT CHANGE	8.951+004
INTERVAL ESTIMATE	-2.840+004
AS PER CENT	6.979+004
PER CENT AVE CHANGE	2.069+004

F-TEST	8.147-001	0.000+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	1.148+000	0.000+000	0.000+000	0.000+000
GROUPS P-S	1.265+000	0.000+000	0.000+000	0.000+000
GROUPS P-C	1.306+000			
GROUPS D-S	-2.817-004			
GROUPS D-C	-2.730-003			
GROUPS S-C	-2.688-003			

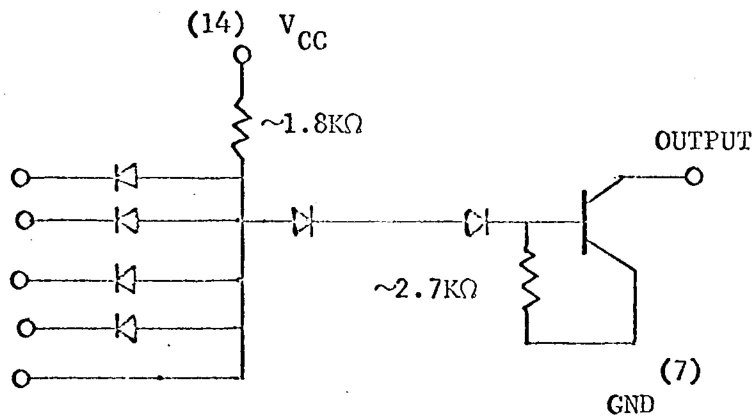
CODE μM400

	CGB-2	CGD	CGS	
UNITS	PF	PF	PF	
GROUP P				
NUMBER	5	5	5	
INITIAL MEAN	2.437+000	2.126+000	2.220+000	
AVERAGE CHANGE	-2.870-001	9.940-002	-2.120-002	
STD OF MEAN	6.128-001	4.204-002	2.303-001	
AVE PER CENT CHANGE	-9.189+000	4.766+000	-4.853-001	
INTERVAL ESTIMATE	-3.970+001	2.479+000	-1.248+001	
AS PER CENT	1.615+001	6.870+000	1.057+001	
PER CENT AVE CHANGE	-1.178+001	4.675+000	-9.550-001	
GROUP D				
NUMBER	5	5	5	
INITIAL MEAN	2.131+000	2.188+000	2.278+000	
AVERAGE CHANGE	-3.820-002	-1.340-002	-1.094-001	
STD OF MEAN	2.747-002	2.277-001	4.668-001	
AVE PER CENT CHANGE	-1.754+000	6.135-002	-2.779+000	
INTERVAL ESTIMATE	-3.223+000	-1.216+001	-2.755+001	
AS PER CENT	-3.611-001	1.094+001	1.795+001	
PER CENT AVE CHANGE	-1.792+000	-6.123-001	-4.802+000	
GROUP S				
NUMBER	5	5	5	
INITIAL MEAN	2.221+000	2.153+000	2.128+000	
AVERAGE CHANGE	-6.200-003	1.466-001	1.434-001	
STD OF MEAN	3.605-002	6.952-002	4.243-002	
AVE PER CENT CHANGE	-2.489-001	6.901+000	6.797+000	
INTERVAL ESTIMATE	-2.082+000	3.224+000	4.526+000	
AS PER CENT	1.523+000	1.040+001	8.954+000	
PER CENT AVE CHANGE	-2.792-001	6.810+000	6.740+000	
GROUP C				
NUMBER	5	5	5	
INITIAL MEAN	2.156+000	2.107+000	2.087+000	
AVERAGE CHANGE	-3.020-002	9.460-002	4.560-002	
STD OF MEAN	2.282-002	1.068-001	2.455-002	
AVE PER CENT CHANGE	-1.380+000	4.628+000	2.220+000	
INTERVAL ESTIMATE	-2.576+000	-1.137+000	8.785-001	
AS PER CENT	-2.253-001	1.012+001	3.491+000	
PER CENT AVE CHANGE	-1.401+000	4.489+000	2.185+000	
F-TEST	1.148+000	1.639+000	1.043+000	0.000+000
T-TEST				
GROUPS P-D	-1.431+000	1.509+000	5.964-001	0.000+000
GROUPS P-S	-1.615+000	-6.315-001	-1.113+000	0.000+000
GROUPS P-C	-1.477+000	6.422-002	-4.517-001	
GROUPS D-S	-1.840-001	-2.141+000	-1.710+000	
GROUPS D-C	-4.600-002	-1.445+000	-1.048+000	
GROUPS S-C	1.380-001	6.957-001	6.614-001	

TEST RESULT SUMMARY SHEET

Circuit Identification Code: Radiation Incorporated RD210

Circuit Diagram:



Circuit Description:

Function: DTL NAND/NOR Gate
Process: Passivated Epitaxial and Dielectric Isolation
Advertised Speed: Propagation Delay
7 ns Typical

TEST RESULT SUMMARY SHEET (Continued) Code RD210

IN SITE DATA

Electron Fluence:
To First Failure 4.15×10^{14} e/cm^2
Test Total 4.6×10^{14} e/cm^2

Failure Mode: V_{zero} exceeded 0.400 Volts

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	72 F	80 F	74 F	
V_{zero}	Mean Value (Volts)	.295	.381	.380	.382
	Percent Change in Mean Value (%)	----	29.1	28.8	29.5
	Spread min./max.	.289/.313	.345/.403	.344/.400	.347/.402
V_{one}	Mean Value (Volts)	4.9	4.11	4.12	4.13
	Percent Change in Mean Value (%)	----	-16.1	-15.9	-15.7
	Spread min./max.	4.9/4.9	4.09/4.16	4.10/4.17	4.11/4.18
Pulsed Circuits	Temperature	72 F	80 F	74 F	
V_{zero} Static Mode	Mean Value (Volts)	.293	----	.338*	.384*
	Precent Change in Mean Value (%)	----	----	15.3	31.0
	Spread min./max. (Volts)	.279/.313	----	.315/.364	.360/.413
V_{zero} Pulsed Mode	Mean Value (Volts)	.30	.37	.34	----
	Percent Change in Mean Value (%)	----	23.3	13.3	----
	Spread min./max. (Volts)	.25/.32	.32/.39	.32/.39	----
Dynamic Circuits	Temperature	72 F	80 F	74 F	
Multistage Propagation Delay	Mean Value (f^{-1} ns)	100	110	110	110
	Percent Change in Mean Value (%)	----	10	10	10

*After 15 minutes continuous operation.

CODE RD210

	VMX ZERO-1	VMIN ONE-1	VMX ZERO-8	VMIN ONE-8
UNITS	VOLTS	VOLTS	VOLTS	VOLTS
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	1.315+000	1.387+000	1.383+000	1.565+000
AVERAGE CHANGE	-5.940-002	-5.140-002	-4.460-002	1.760-002
STD OF MEAN	3.921-003	6.354-003	6.548-003	1.863-002
AVE PER CENT CHANGE	-4.519+000	-3.703+000	-3.223+000	1.121+000
INTERVAL ESTIMATE	-4.849+000	-4.213+000	-3.751+000	-1.976-001
AS PER CENT	-4.187+000	-3.196+000	-2.699+000	2.447+000
PER CENT AVE CHANGE	-4.518+000	-3.705+000	-3.225+000	1.125+000
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	1.355+000	1.429+000	1.424+000	1.627+000
AVERAGE CHANGE	-5.760-002	-5.300-002	-4.680-002	8.800-003
STD OF MEAN	2.220-002	2.129-002	1.800-002	3.967-002
AVE PER CENT CHANGE	-4.230+000	-3.691+000	-3.272+000	5.468-001
INTERVAL ESTIMATE	-6.071+000	-5.362+000	-4.689+000	-2.166+000
AS PER CENT	-2.432+000	-2.055+000	-1.883+000	3.248+000
PER CENT AVE CHANGE	-4.252+000	-3.708+000	-3.286+000	5.409-001
GROUP S				
NUMBER	4	4	4	4
INITIAL MEAN	1.334+000	1.408+000	1.405+000	1.594+000
AVERAGE CHANGE	-5.800-002	-5.200-002	-4.350-002	4.250-003
STD OF MEAN	7.717-003	6.600-003	6.000-003	9.586-003
AVE PER CENT CHANGE	-4.341+000	-3.694+000	-3.101+000	2.667-001
INTERVAL ESTIMATE	-5.146+000	-4.338+000	-3.685+000	-5.618-001
AS PER CENT	-3.552+000	-3.046+000	-2.508+000	1.095+000
PER CENT AVE CHANGE	-4.349+000	-3.692+000	-3.097+000	2.666-001
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	1.331+000	1.403+000	1.403+000	1.601+000
AVERAGE CHANGE	5.800-003	4.400-003	7.000-003	9.600-003
STD OF MEAN	5.385-003	1.275-003	4.031-003	9.441-003
AVE PER CENT CHANGE	4.373-001	3.149-001	5.023-001	5.938-001
INTERVAL ESTIMATE	-1.350-002	2.128-001	1.799-001	-5.516-002
AS PER CENT	8.853-001	4.146-001	8.181-001	1.255+000
PER CENT AVE CHANGE	4.359-001	3.137-001	4.990-001	5.998-001
F-TEST	4.094+001	3.503+001	3.831+001	3.212-001
T-TEST				
GROUPS P-D	-2.561-001	2.389-001	3.726-001	6.614-001
GROUPS P-S	-1.878-001	8.446-002	-1.757-001	9.460-001
GROUPS P-C	-9.275+000	-8.331+000	-8.740+000	6.013-001
GROUPS D-S	5.365-002	-1.408-001	-5.270-001	3.224-001
GROUPS D-C	-9.019+000	-8.570+000	-9.113+000	-6.013-002
GROUPS S-C	-8.557+000	-7.939+000	-8.065+000	-3.791-001

CODE RD210

IIN DRIVE

UNITS MA

GROUP P

NUMBER	20
INITIAL MEAN	2.440+000
AVERAGE CHANGE	-2.250-002
STD OF MEAN	1.194-002
AVE PER CENT CHANGE	-9.277-001
INTERVAL ESTIMATE	-1.145+000
AS PER CENT	-6.987-001
PER CENT AVE CHANGE	-9.219-001

GROUP D

NUMBER	20
INITIAL MEAN	2.370+000
AVERAGE CHANGE	-2.300-002
STD OF MEAN	1.336-002
AVE PER CENT CHANGE	-9.657-001
INTERVAL ESTIMATE	-1.228+000
AS PER CENT	-7.134-001
PER CENT AVE CHANGE	-9.705-001

GROUP S

NUMBER	19
INITIAL MEAN	2.355+000
AVERAGE CHANGE	-2.421-002
STD OF MEAN	1.654-002
AVE PER CENT CHANGE	-1.007+000
INTERVAL ESTIMATE	-1.357+000
AS PER CENT	-6.985-001
PER CENT AVE CHANGE	-1.028+000

GROUP C

NUMBER	20
INITIAL MEAN	2.553+000
AVERAGE CHANGE	2.910-012
STD OF MEAN	8.807-003
AVE PER CENT CHANGE	1.508-004
INTERVAL ESTIMATE	-1.573-001
AS PER CENT	1.573-001
PER CENT AVE CHANGE	1.140-010

F-TEST	1.704+001	0.000+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	1.257-001	0.000+000	0.000+000	0.000+000
GROUPS P-S	4.246-001	0.000+000	0.000+000	0.000+000
GROUPS P-C	-5.659+000			
GROUPS D-S	3.005-001			
GROUPS D-C	-5.784+000			
GROUPS S-C	-6.010+000			

CODE RD210

	IIN LEAK	IOUT DRIVE	V FORWARD	VSAT
UNITS	AMPS	MA	VOLTS	VOLTS
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	1.636-009	3.082+001	7.422-001	3.006-001
AVERAGE CHANGE	2.840-010	-5.540+000	4.800-003	4.780-002
STD OF MEAN	4.600-010	1.125+000	2.424-003	2.832-002
AVE PER CENT CHANGE	1.267+001	-1.794+001	6.456-001	1.591+001
INTERVAL ESTIMATE	-1.386+001	-2.203+001	2.841-001	5.440+000
AS PER CENT	4.858+001	-1.392+001	1.009+000	2.636+001
PER CENT AVE CHANGE	1.736+001	-1.798+001	6.467-001	1.590+001
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	1.659-007	3.070+001	7.378-001	3.176-001
AVERAGE CHANGE	2.622-007	-4.160+000	5.800-003	3.600-002
STD OF MEAN	6.487-007	2.075+000	2.151-003	1.792-002
AVE PER CENT CHANGE	4.693+001	-1.305+001	7.866-001	1.102+001
INTERVAL ESTIMATE	-2.761+002	-2.105+001	4.625-001	5.069+000
AS PER CENT	5.920+002	-6.047+000	1.110+000	1.760+001
PER CENT AVE CHANGE	1.580+002	-1.355+001	7.861-001	1.134+001
GROUP S				
NUMBER	4	5	4	5
INITIAL MEAN	1.522-006	3.026+001	7.374-001	3.154-001
AVERAGE CHANGE	-2.500-011	-4.020+000	6.250-003	3.300-002
STD OF MEAN	3.037-010	2.753+000	4.558-003	4.809-003
AVE PER CENT CHANGE	4.547-011	-1.276+001	8.499-001	1.057+001
INTERVAL ESTIMATE	-2.913-002	-2.339+001	-4.148-003	8.770+000
AS PER CENT	2.585-002	-3.184+000	1.699+000	1.216+001
PER CENT AVE CHANGE	-1.642-003	-1.328+001	8.476-001	1.046+001
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	4.000-005	3.016+001	7.380-001	3.154-001
AVERAGE CHANGE	1.360-010	2.200-001	6.200-003	-5.000-003
STD OF MEAN	2.135-010	5.087-001	9.131-003	7.624-003
AVE PER CENT CHANGE	2.000+001	9.358-001	8.369-001	-1.420+000
INTERVAL ESTIMATE	-2.528-004	-1.143+000	-5.337-001	-4.269+000
AS PER CENT	9.328-004	2.602+000	2.214+000	1.099+000
PER CENT AVE CHANGE	3.400-004	7.294-001	8.401-001	-1.585+000
F-TEST	9.392-001	1.159+001	9.411-002	1.086+001
T-TEST				
GROUPS P-D	-1.382+000	-1.333+000	-3.287-001	1.202+000
GROUPS P-S	1.537-003	-1.468+000	-4.493-001	1.508+000
GROUPS P-C	7.811-004	-5.562+000	-4.601-001	5.379+000
GROUPS D-S	1.305+000	-1.352-001	-1.394-001	3.056-001
GROUPS D-C	1.383+000	-4.229+000	-1.315-001	4.177+000
GROUPS S-C	-8.011-004	-4.094+000	1.549-002	3.871+000

CODE RD210

	T-RISE	T-FALL	T-DELAY	T-STORE
UNITS	NS	NS	NS	NS
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	6.500+000	8.200+001	5.800+000	1.080+001
AVERAGE CHANGE	1.200+000	-2.400+000	4.000-001	3.000-001
STD OF MEAN	3.062-001	2.915+000	2.500-001	3.062-001
AVE PER CENT CHANGE	1.873+001	-2.809+000	7.121+000	2.774+000
INTERVAL ESTIMATE	1.323+001	-6.875+000	2.110+000	-3.703-001
AS PER CENT	2.369+001	1.021+000	1.168+001	5.926+000
PER CENT AVE CHANGE	1.846+001	-2.927+000	6.897+000	2.778+000
GROUP D				
NUMBER	5	5	5	5
INITIAL MEAN	8.100+000	8.120+001	6.200+000	1.030+001
AVERAGE CHANGE	8.000-001	-4.000-001	4.000-001	6.000-001
STD OF MEAN	1.225+000	1.871+000	4.677-001	6.124-001
AVE PER CENT CHANGE	9.917+000	-4.750-001	6.732+000	5.905+000
INTERVAL ESTIMATE	-6.913+000	-3.051+000	-1.925+000	-7.765-001
AS PER CENT	2.667+001	2.066+000	1.483+001	1.243+001
PER CENT AVE CHANGE	9.877+000	-4.926-001	6.452+000	5.825+000
GROUP S				
NUMBER	4	4	4	4
INITIAL MEAN	6.600+000	8.080+001	5.800+000	1.040+001
AVERAGE CHANGE	1.125+000	-1.500+000	6.250-001	5.000-001
STD OF MEAN	5.528-001	2.906+000	2.887-001	4.714-001
AVE PER CENT CHANGE	1.731+001	-1.798+000	1.136+001	4.762+000
INTERVAL ESTIMATE	5.506+000	-6.812+000	3.918+000	-1.438+000
AS PER CENT	2.859+001	3.099+000	1.763+001	1.105+001
PER CENT AVE CHANGE	1.705+001	-1.856+000	1.078+001	4.808+000
GROUP C				
NUMBER	5	5	5	5
INITIAL MEAN	6.900+000	8.240+001	5.900+000	1.080+001
AVERAGE CHANGE	1.000-001	-3.200+000	2.000-001	9.000-001
STD OF MEAN	2.500-001	2.000+000	3.062-001	4.677-001
AVE PER CENT CHANGE	1.176+000	-3.847+000	3.357+000	8.452+000
INTERVAL ESTIMATE	-2.574+000	-6.579+000	-2.373+000	3.525+000
AS PER CENT	5.472+000	-1.188+000	9.152+000	1.314+001
PER CENT AVE CHANGE	1.449+000	-3.883+000	3.390+000	8.333+000
F-TEST	3.065+000	1.538+000	1.449+000	1.725+000
T-TEST				
GROUPS P-D	1.001+000	-1.462+000	0.000+000	-1.118+000
GROUPS P-S	1.770-001	-6.202-001	-1.103+000	-7.027-001
GROUPS P-C	2.753+000	5.847-001	1.040+000	-2.236+000
GROUPS D-S	-7.668-001	7.580-001	-1.103+000	3.514-001
GROUPS D-C	1.752+000	2.046+000	1.040+000	-1.118+000
GROUPS S-C	2.418+000	1.171+000	2.083+000	-1.405+000

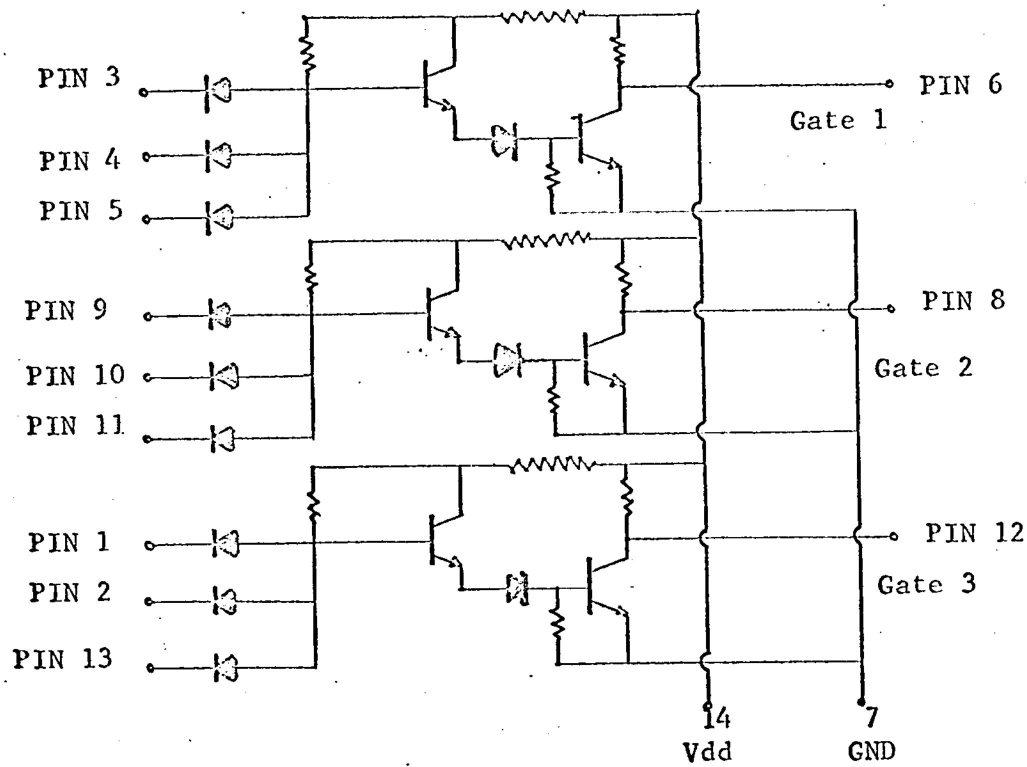
CODE RD210

	RIN	GAIN		
UNITS	K-OHMS			
GROUP P				
NUMBER	5	5		
INITIAL MEAN	1.669+000	3.230+001		
AVERAGE CHANGE	3.980-002	-9.940+000		
STD OF MEAN	7.461-002	4.579+000		
AVE PER CENT CHANGE	2.465+000	-2.969+001		
INTERVAL ESTIMATE	-2.580+000	-4.652+001		
AS PER CENT	7.350+000	-1.503+001		
PER CENT AVE CHANGE	2.385+000	-3.077+001		
GROUP D				
NUMBER	5	5		
INITIAL MEAN	1.754+000	3.230+001		
AVERAGE CHANGE	1.080-002	-1.366+001		
STD OF MEAN	7.640-003	1.254+001		
AVE PER CENT CHANGE	6.241-001	-3.923+001		
INTERVAL ESTIMATE	1.321-001	-8.539+001		
AS PER CENT	1.100+000	8.104-001		
PER CENT AVE CHANGE	6.159-001	-4.229+001		
GROUP S				
NUMBER	5	5		
INITIAL MEAN	1.768+000	3.326+001		
AVERAGE CHANGE	1.280-002	-9.920+000		
STD OF MEAN	2.000-003	2.380+000		
AVE PER CENT CHANGE	7.331-001	-2.958+001		
INTERVAL ESTIMATE	5.983-001	-3.777+001		
AS PER CENT	8.495-001	-2.188+001		
PER CENT AVE CHANGE	7.239-001	-2.983+001		
GROUP C				
NUMBER	5	5		
INITIAL MEAN	1.642+000	3.114+001		
AVERAGE CHANGE	-1.900-002	-1.380+000		
STD OF MEAN	4.008-002	1.634+000		
AVE PER CENT CHANGE	-1.183+000	-4.796+000		
INTERVAL ESTIMATE	-3.868+000	-1.026+001		
AS PER CENT	1.554+000	1.396+000		
PER CENT AVE CHANGE	-1.157+000	-4.432+000		
F-TEST	1.996+000	3.629+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	1.205+000	9.631-001	0.000+000	0.000+000
GROUPS P-S	1.122+000	-5.178-003	0.000+000	0.000+000
GROUPS P-C	2.444+000	-2.216+000		
GROUPS D-S	-8.313-002	-9.683-001		
GROUPS D-C	1.239+000	-3.179+000		
GROUPS S-C	1.322+000	-2.211+000		

TEST RESULT SUMMARY SHEET

Circuit Identification Code: Motorola DTL-EPIC Gate

Circuit Diagram:



Circuit Description:

Function: DTL NAND Gate
Process: EPIC (Dielectric Isolation)
Approximate Speed: Propagation Delay
5 ns Minimum
80 ns Maximum

TEST RESULT SUMMARY SHEET (Continued)

Code DTL-EPIC

IN SITE DATA

Electron Fluence:
- To First Failure 3.88×10^{15} e/cm^2
- Test Total 3.94×10^{15} e/cm^2

Failure Mode: V_{zero} exceeded 0.40 volts for a B-3M device

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	72 F	83 F	75 F	
V_{zero}	Mean Value (Volts)	.047	.100	.100	.104
	Percent Change in Mean Value (%)	----	112	112	121
	Spread min./max.	.047	.100	.100	.104
V_{one}	Mean Value (Volts)	.286	.285	.286	.290
	Percent Change in Mean Value (%)	----	0.3	0	1.4
	Spread min./max.	.286	.285	.286	.290
Pulsed Circuits	Temperature	72 F	88 F	75 F	
V_{zero} Static Mode	Mean Value (Volts)	.112	----	.383*	.350*
	Percent Change in Mean Value (%)	----	----	242	212
	Spread min./max.	.096/.125	----	.192/.970	.228/.673
V_{one} Pulsed Mode	Mean Value (Volts)	.14	.642	----	.990
	Percent Change in Mean Value (%)	----	358	----	607
	Spread min./max.	.14/.14	.250/1.57	----	.96/2.0
Dynamic Circuits	Temperature	72 F	88 F	75 F	
Multistage Propagation Delay	Mean Value (f^{-1} ns)	310	180	120	40
	Percent Change in Mean Value (%)	----	-41.9	-61.3	-87

*After 15 minutes continuous operation.

CODE DTL-EPIC

	VMINONE-1	VMXZERO-1	VMINONE-9	VMXZERO-9
UNITS	VOLTS	VOLTS	VOLTS	VOLTS
GROUP P				
NUMBER	5	5	4	5
INITIAL MEAN	1.335+000	1.296+000	1.459+000	1.396+000
AVERAGE CHANGE	9.660-002	7.440-002	2.012-001	1.110-001
STD OF MEAN	1.427-002	3.027-002	7.349-002	3.019-002
AVE PER CENT CHANGE	7.225+000	5.757+000	1.377+001	7.921+000
INTERVAL ESTIMATE	6.050+000	3.147+000	6.852+000	5.551+000
AS PER CENT	8.424+000	8.333+000	2.073+001	1.035+001
PER CENT AVE CHANGE	7.237+000	5.740+000	1.379+001	7.952+000
GROUP D				
NUMBER	2	2	2	2
INITIAL MEAN	1.356+000	1.327+000	1.439+000	1.419+000
AVERAGE CHANGE	8.950-002	6.150-002	1.665-001	4.900-002
STD OF MEAN	1.000-003	1.000-003	2.300-002	9.200-002
AVE PER CENT CHANGE	6.603+000	4.635+000	1.118+001	3.421+000
INTERVAL ESTIMATE	6.134+000	4.156+000	1.368+000	-3.772+001
AS PER CENT	7.071+000	5.113+000	2.099+001	4.463+001
PER CENT AVE CHANGE	6.603+000	4.635+000	1.118+001	3.452+000
GROUP S				
NUMBER	1	1	1	1
INITIAL MEAN	1.319+000	1.289+000	1.436+000	1.376+000
AVERAGE CHANGE	1.000-001	6.300-002	1.560-001	9.800-002
STD OF MEAN	0.000+000	0.000+000	0.000+000	0.000+000
AVE PER CENT CHANGE	7.582+000	4.888+000	1.086+001	7.122+000
INTERVAL ESTIMATE	7.582+000	4.888+000	1.086+001	7.122+000
AS PER CENT	7.582+000	4.888+000	1.086+001	7.122+000
PER CENT AVE CHANGE	7.582+000	4.888+000	1.086+001	7.122+000
GROUP C				
NUMBER	2	2	2	2
INITIAL MEAN	1.353+000	1.324+000	1.499+000	1.415+000
AVERAGE CHANGE	2.950-002	2.400-002	-2.500-003	-3.500-003
STD OF MEAN	1.000-003	6.000-003	3.000-003	3.000-003
AVE PER CENT CHANGE	2.180+000	1.809+000	-1.688-001	-2.500-001
INTERVAL ESTIMATE	1.710+000	-1.066+000	-1.438+000	-1.594+000
AS PER CENT	2.649+000	4.692+000	1.105+000	1.100+000
PER CENT AVE CHANGE	2.180+000	1.813+000	-1.668-001	-2.473-001
F-TEST	2.151+001	2.467+000	7.674+000	5.783+000
T-TEST				
GROUPS P-D	8.139-001	6.954-001	8.051-001	2.146+000
GROUPS P-S	-2.977-001	4.694-001	8.121-001	3.437-001
GROUPS P-C	7.692+000	2.717+000	4.721+000	3.964+000
GROUPS D-S	-8.223-001	-5.524-002	1.720-001	-1.159+000
GROUPS D-C	5.755+000	1.691+000	3.391+000	1.521+000
GROUPS S-C	5.521+000	1.436+000	2.597+000	2.400+000

CODE DTL-EPIC

UNITS	IINDRIVE AMP	IINLEAK AMP		
GROUP P				
NUMBER	15	5		
INITIAL MEAN	1.152-003	2.080-010		
AVERAGE CHANGE	-7.333-006	6.700-010		
STD OF MEAN	4.738-006	4.371-010		
AVE PER CENT CHANGE	-6.791-001	3.727+002		
INTERVAL ESTIMATE	-8.566-001	8.877+001		
AS PER CENT	-4.165-001	5.555+002		
PER CENT AVE CHANGE	-6.366-001	3.221+002		
GROUP D				
NUMBER	6	2		
INITIAL MEAN	9.100-004	1.501-007		
AVERAGE CHANGE	-1.000-005	-6.479-008		
STD OF MEAN	0.000+000	1.304-007		
AVE PER CENT CHANGE	-1.101+000	6.233+001		
INTERVAL ESTIMATE	-1.099+000	-5.951+002		
AS PER CENT	-1.099+000	5.088+002		
PER CENT AVE CHANGE	-1.099+000	-4.316+001		
GROUP S				
NUMBER	3	1		
INITIAL MEAN	1.440-003	1.000-010		
AVERAGE CHANGE	-1.000-005	7.000-010		
STD OF MEAN	0.000+000	0.000+000		
AVE PER CENT CHANGE	-6.944-001	7.000+002		
INTERVAL ESTIMATE	-6.944-001	7.000+002		
AS PER CENT	-6.944-001	7.000+002		
PER CENT AVE CHANGE	-6.944-001	7.000+002		
GROUP C				
NUMBER	6	2		
INITIAL MEAN	1.270-003	5.500-009		
AVERAGE CHANGE	0.000+000	-1.050-009		
STD OF MEAN	0.000+000	1.900-009		
AVE PER CENT CHANGE	0.000+000	-1.500+001		
INTERVAL ESTIMATE	0.000+000	-2.386+002		
AS PER CENT	0.000+000	2.004+002		
PER CENT AVE CHANGE	0.000+000	-1.909+001		
F-TEST	1.103+001	1.592+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	1.644+000	2.078+000	0.000+000	0.000+000
GROUPS P-S	1.255+000	-7.273-004	0.000+000	0.000+000
GROUPS P-C	-4.520+000	5.460-002		
GROUPS D-S	0.000+000	-1.420+000		
GROUPS D-C	-5.157+000	-1.693+000		
GROUPS S-C	-4.210+000	3.795-002		

CODE DTL-EPIC

UNITS	IOUTDRIVE AMP	R PULL-UP OHMS		
GROUP P				
NUMBER	5	5		
INITIAL MEAN	1.670-002	4.815+003		
AVERAGE CHANGE	-1.284-002	1.680+000		
STD OF MEAN	1.542-003	2.122+000		
AVE PER CENT CHANGE	-7.727+001	3.406-002		
INTERVAL ESTIMATE	-8.714+001	-1.404-002		
AS PER CENT	-6.663+001	8.383-002		
PER CENT AVE CHANGE	-7.689+001	3.489-002		
GROUP D				
NUMBER	2	2		
INITIAL MEAN	1.450-002	4.747+003		
AVERAGE CHANGE	-1.145-002	-1.300+000		
STD OF MEAN	2.500-003	1.200+000		
AVE PER CENT CHANGE	-7.673+001	-2.765-002		
INTERVAL ESTIMATE	-1.885+002	-1.880-001		
AS PER CENT	3.057+001	1.332-001		
PER CENT AVE CHANGE	-7.897+001	-2.739-002		
GROUP S				
NUMBER	1	1		
INITIAL MEAN	1.830-002	4.884+003		
AVERAGE CHANGE	-1.340-002	4.800+000		
STD OF MEAN	0.000+000	0.000+000		
AVE PER CENT CHANGE	-7.322+001	9.827-002		
INTERVAL ESTIMATE	-7.322+001	9.827-002		
AS PER CENT	-7.322+001	9.827-002		
PER CENT AVE CHANGE	-7.322+001	9.827-002		
GROUP C				
NUMBER	2	2		
INITIAL MEAN	1.370-002	4.270+003		
AVERAGE CHANGE	-5.000-005	-2.000+000		
STD OF MEAN	1.000-004	4.000-001		
AVE PER CENT CHANGE	-3.521-001	-4.673-002		
INTERVAL ESTIMATE	-5.002+000	-1.064-001		
AS PER CENT	4.272+000	1.267-002		
PER CENT AVE CHANGE	-3.650-001	-4.684-002		
F-TEST	4.730+001	5.810+000	0.000+000	0.000+000
T-TEST				
GROUPS P-D	-1.242+000	2.237+000	0.000+000	0.000+000
GROUPS P-S	3.821-001	-1.789+000	0.000+000	0.000+000
GROUPS P-C	-1.142+001	2.763+000		
GROUPS D-S	1.190+000	-3.128+000		
GROUPS D-C	-8.520+000	4.397-001		
GROUPS S-C	-8.146+000	3.487+000		

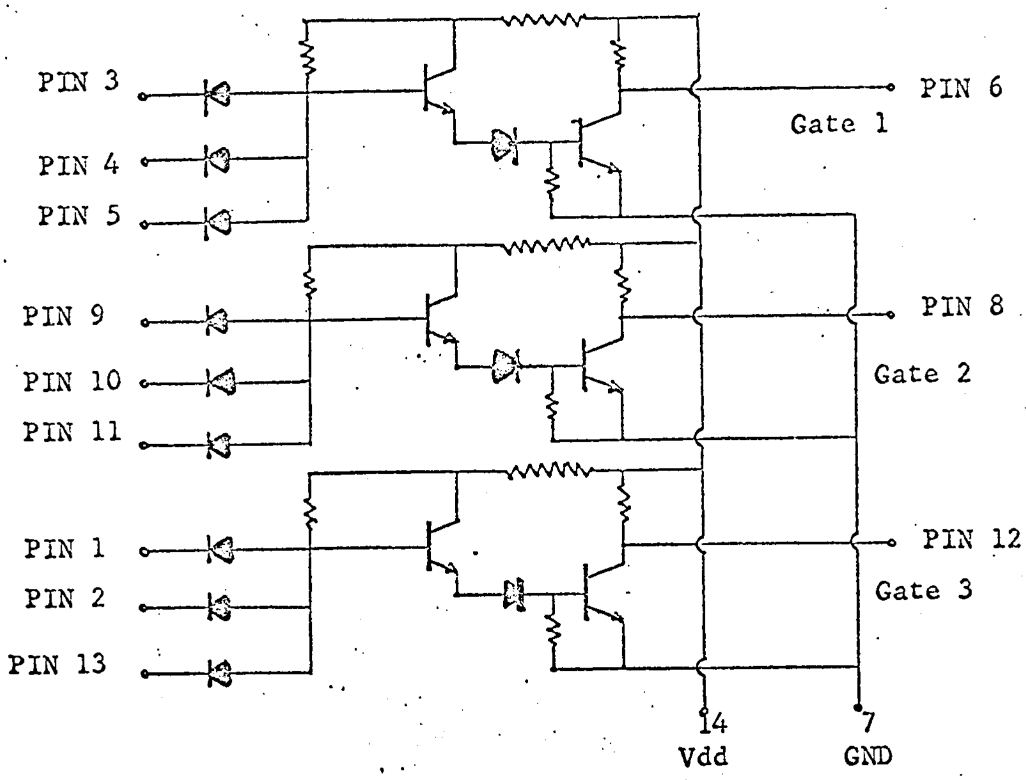
CODE DTL-EPIC

	T-RISE	T-FALL	T-DELAY	T-STORE
UNITS	NS	NS	NS	NS
GROUP P				
NUMBER	5	5	5	5
INITIAL MEAN	1.120+001	2.190+002	1.030+001	8.400+001
AVERAGE CHANGE	5.100+000	-2.000+001	0.000+000	-6.200+001
STD OF MEAN	4.096+000	2.305+001	3.953-001	2.950+001
AVE PER CENT CHANGE	4.346+001	-9.036+000	-1.003-001	-7.219+001
INTERVAL ESTIMATE	4.922+000	-2.082+001	-4.261+000	-1.128+002
AS PER CENT	8.615+001	2.554+000	4.261+000	-3.482+001
PER CENT AVE CHANGE	4.554+001	-9.132+000	0.000+000	-7.381+001
GROUP D				
NUMBER	2	2	2	2
INITIAL MEAN	1.300+001	2.050+002	1.175+001	1.590+002
AVERAGE CHANGE	6.000+000	-7.500+000	0.000+000	-1.360+002
STD OF MEAN	0.000+000	2.500+001	0.000+000	2.200+002
AVE PER CENT CHANGE	4.875+001	-3.512+000	0.000+000	-7.264+001
INTERVAL ESTIMATE	4.615+001	-8.113+001	0.000+000	-9.646+002
AS PER CENT	4.615+001	7.382+001	0.000+000	7.935+002
PER CENT AVE CHANGE	4.615+001	-3.659+000	0.000+000	-8.553+001
GROUP S				
NUMBER	1	1	1	1
INITIAL MEAN	7.500+000	2.250+002	8.500+000	1.300+002
AVERAGE CHANGE	3.000+000	-2.500+001	0.000+000	-1.060+002
STD OF MEAN	0.000+000	0.000+000	0.000+000	0.000+000
AVE PER CENT CHANGE	4.000+001	-1.111+001	0.000+000	-8.154+001
INTERVAL ESTIMATE	4.000+001	-1.111+001	0.000+000	-8.154+001
AS PER CENT	4.000+001	-1.111+001	0.000+000	-8.154+001
PER CENT AVE CHANGE	4.000+001	-1.111+001	0.000+000	-8.154+001
GROUP C				
NUMBER	2	2	2	2
INITIAL MEAN	1.267+001	2.033+002	1.117+001	1.753+002
AVERAGE CHANGE	2.300-001	-1.750+001	-2.500-001	0.000+000
STD OF MEAN	5.000-001	1.500+001	5.000-001	0.000+000
AVE PER CENT CHANGE	2.500+000	-8.791+000	-2.500+000	0.000+000
INTERVAL ESTIMATE	-2.310+001	-5.547+001	-3.069+001	0.000+000
AS PER CENT	2.705+001	3.826+001	2.621+001	0.000+000
PER CENT AVE CHANGE	1.974+000	-8.607+000	-2.239+000	0.000+000
F-TEST	1.601+000	2.706-001	3.200-001	1.491+000
T-TEST				
GROUPS P-D	-3.592-001	-7.939-001	0.000+000	1.319+000
GROUPS P-S	6.400-001	2.425-001	0.000+000	5.989-001
GROUPS P-C	1.935+000	-1.588-001	9.258-001	-1.105+000
GROUPS D-S	8.178-001	7.593-001	0.000+000	-3.653-001
GROUPS D-C	1.920+000	5.314-001	7.746-001	-2.028+000
GROUPS S-C	7.497-001	-3.254-001	6.325-001	-1.291+000

TEST RESULT SUMMARY SHEET

Circuit Identification Code: Motorola MC962

Circuit Diagram:



Circuit Description:

Function: DTL NAND Gate
Process: Epitaxial (Monolithic)
Advertised Speed: Average Propagation Dealy
12 Minimum

TEST RESULT SUMMARY SHEET (Continued)

Code MC962

IN SITE DATA

Electron Fluence:
- To First Failure 3.88×10^{15} e/cm^2
- Test Total 3.94×10^{15} e/cm^2

Failure Mode:

Monitored Parameters:

		Initial	Final	Post Rad. In Site	Post Rad. 1 week
Static Circuits	Temperature	72 F	83 F	75 F	
V_{zero}	Mean Value (Volts)	.191*	.315	.349	.315
	Percent Change in Mean Value (%)	----	66.0	82.7	66.0
	Spread min./max.	.187/.193	.262/.407	.262/.510	.265/.402
V_{one}	Mean Value (Volts)	.279	2.75	2.76	2.78
	Percent Change in Mean Value (%)	----	-1.4	-1.1	-.4
	Spread min./max.	2.75/2.81	2.72/2.78	2.73/2.78	2.74/2.79
Pulsed Circuits	Temperature				
	No B-3M Circuits in Pulsed Group				
	No B-3M Circuits in Pulsed Group				
Dynamic Circuits	Temperature	72 F	88 F	75 F	
Multistage Propa-	Mean Value (f^{-1} ns)	310	180	120	40
gation Delay	Percent Change in Mean Value (%)	---	-41.9	-61.3	-87

*The V_N pin on device No. 2 came unwelded and V_{zero} data was not taken.

CODE MC962

		VMIN-1	VMXZERO-1	VMINONE-9	VMX-ZERO-9
	UNITS	VOLTS	VOLTS	VOLTS	VOLTS
GROUP P					
NUMBER		0	0	0	0
INITIAL MEAN		0.000+000	0.000+000	0.000+000	0.000+000
AVERAGE CHANGE		0.000+000	0.000+000	0.000+000	0.000+000
STD OF MEAN		-0.000+000	-0.000+000	-0.000+000	-0.000+000
AVE PER CENT CHANGE		0.000+000	0.000+000	0.000+000	0.000+000
INTERVAL ESTIMATE		0.000+000	0.000+000	0.000+000	0.000+000
AS PER CENT		0.000+000	0.000+000	0.000+000	0.000+000
PER CENT AVE CHANGE		0.000+000	0.000+000	0.000+000	0.000+000
GROUP D					
NUMBER		3	3	3	3
INITIAL MEAN		1.443+000	1.404+000	1.594+000	1.504+000
AVERAGE CHANGE		2.267-002	1.400-002	7.433-002	4.100-002
STD OF MEAN		4.611-002	2.658-002	1.460-001	8.062-002
AVE PER CENT CHANGE		1.574+000	9.984-001	4.666+000	2.729+000
INTERVAL ESTIMATE		-4.910+000	-2.842+000	-1.392+001	-8.147+000
AS PER CENT		8.051+000	4.836+000	2.325+001	1.360+001
PER CENT AVE CHANGE		1.570+000	9.969-001	4.663+000	2.726+000
GROUP S					
NUMBER		4	4	4	4
INITIAL MEAN		1.423+000	1.386+000	1.559+000	1.478+000
AVERAGE CHANGE		6.100-002	3.700-002	2.367-001	1.140-001
STD OF MEAN		1.011-002	8.000-003	8.427-002	2.604-002
AVE PER CENT CHANGE		4.280+000	2.665+000	1.511+001	7.695+000
INTERVAL ESTIMATE		3.307+000	1.874+000	7.737+000	5.285+000
AS PER CENT		5.265+000	3.464+000	2.263+001	1.014+001
PER CENT AVE CHANGE		4.286+000	2.669+000	1.518+001	7.713+000
GROUP C					
NUMBER		3	3	3	3
INITIAL MEAN		1.426+000	1.389+000	1.563+000	1.480+000
AVERAGE CHANGE		3.700-002	2.067-002	1.167-001	6.633-002
STD OF MEAN		3.414-002	1.995-002	1.201-001	6.728-002
AVE PER CENT CHANGE		2.605+000	1.493+000	7.518+000	4.510+000
INTERVAL ESTIMATE		-2.262+000	-1.425+000	-8.124+000	-4.740+000
AS PER CENT		7.453+000	4.400+000	2.305+001	1.371+001
PER CENT AVE CHANGE		2.595+000	1.488+000	7.463+000	4.483+000
F-TEST		1.143+000	1.231+000	1.589+000	1.195+000
T-TEST					
GROUPS P-D		-1.415+000	-1.477+000	-1.250+000	-1.366+000
GROUPS P-S		-4.397+000	-4.508+000	-4.597+000	-4.384+000
GROUPS P-C		-2.310+000	-2.181+000	-1.962+000	-2.209+000
GROUPS D-S		-1.809+000	-1.835+000	-2.065+000	-1.838+000
GROUPS D-C		-6.327-001	-4.974-001	-5.034-001	-5.966-001
GROUPS S-C		1.133+000	1.303+000	1.527+000	1.200+000

CODE MC962

	IINDRIVE	IINDRIVE	IINDRIVE	IIN LEAK
UNITS	AMP	AMP	AMP	AMP
GROUP P				
NUMBER	0	0	0	0
INITIAL MEAN	0.000+000	0.000+000	0.000+000	0.000+000
AVERAGE CHANGE	0.000+000	0.000+000	0.000+000	0.000+000
STD OF MEAN	-0.000+000	-0.000+000	-0.000+000	-0.000+000
AVE PER CENT CHANGE	0.000+000	0.000+000	0.000+000	0.000+000
INTERVAL ESTIMATE	0.000+000	0.000+000	0.000+000	0.000+000
AS PER CENT	0.000+000	0.000+000	0.000+000	0.000+000
PER CENT AVE CHANGE	0.000+000	0.000+000	0.000+000	0.000+000
GROUP D				
NUMBER	3	3	3	3
INITIAL MEAN	1.137-003	1.137-003	1.140-003	5.167-010
AVERAGE CHANGE	-1.000-005	-1.000-005	-6.667-006	-2.667-011
STD OF MEAN	2.121-005	2.121-005	2.550-005	2.454-010
AVE PER CENT CHANGE	-8.696-001	-8.696-001	-5.665-001	-7.740+000
INTERVAL ESTIMATE	-4.665+000	-4.665+000	-5.121+000	-1.015+002
AS PER CENT	2.906+000	2.906+000	3.952+000	9.117+001
PER CENT AVE CHANGE	-8.798-001	-8.798-001	-5.848-001	-5.161+000
GROUP S				
NUMBER	4	4	4	4
INITIAL MEAN	1.147-003	1.152-003	1.152-003	4.625-009
AVERAGE CHANGE	-2.750-005	-3.250-005	-3.250-005	2.500-011
STD OF MEAN	5.774-006	5.774-006	5.774-006	8.400-010
AVE PER CENT CHANGE	-2.399+000	-2.819+000	-2.819+000	2.042+001
INTERVAL ESTIMATE	-3.090+000	-3.510+000	-3.510+000	-2.448+001
AS PER CENT	-1.703+000	-2.130+000	-2.130+000	2.556+001
PER CENT AVE CHANGE	-2.397+000	-2.820+000	-2.820+000	5.405-001
GROUP C				
NUMBER	3	3	3	3
INITIAL MEAN	1.167-003	1.167-003	1.167-003	8.348-009
AVERAGE CHANGE	-2.667-005	-2.667-005	-2.667-005	-1.813-010
STD OF MEAN	2.828-005	2.828-005	2.828-005	3.003-009
AVE PER CENT CHANGE	-2.299+000	-2.299+000	-2.299+000	1.099+003
INTERVAL ESTIMATE	-7.203+000	-7.203+000	-7.203+000	-7.513+001
AS PER CENT	2.632+000	2.632+000	2.632+000	7.079+001
PER CENT AVE CHANGE	-2.286+000	-2.286+000	-2.286+000	-2.172+000
F-TEST	7.100-001	1.032+000	1.197+000	1.108-002
T-TEST				
GROUPS P-D	1.017+000	1.017+000	6.311-001	3.058-002
GROUPS P-S	3.228+000	3.815+000	3.553+000	-3.310-002
GROUPS P-C	2.711+000	2.711+000	2.525+000	2.079-001
GROUPS D-S	1.345+000	1.729+000	1.849+000	-4.479-002
GROUPS D-C	1.198+000	1.198+000	1.339+000	1.254-001
GROUPS S-C	-6.404-002	-4.483-001	-4.175-001	1.789-001

CODE MC962

	IOUT DRIVE	RPULL-UP		
UNITS	AMP	OHMS		
GROUP P				
NUMBER	0	0		
INITIAL MEAN	0.000+000	0.000+000		
AVERAGE CHANGE	0.000+000	0.000+000		
STD OF MEAN	-0.000+000	-0.000+000		
AVE PER CENT CHANGE	0.000+000	0.000+000		
INTERVAL ESTIMATE	0.000+000	0.000+000		
AS PER CENT	0.000+000	0.000+000		
PER CENT AVE CHANGE	0.000+000	0.000+000		
GROUP D				
NUMBER	3	3		
INITIAL MEAN	1.010-002	3.141+003		
AVERAGE CHANGE	-2.500-003	6.750+001		
STD OF MEAN	5.093-003	1.524+002		
AVE PER CENT CHANGE	-2.404+001	2.135+000		
INTERVAL ESTIMATE	-1.270+002	-7.695+000		
AS PER CENT	7.753+001	1.199+001		
PER CENT AVE CHANGE	-2.475+001	2.149+000		
GROUP S				
NUMBER	4	4		
INITIAL MEAN	1.072-002	3.478+003		
AVERAGE CHANGE	-7.275-003	1.829+002		
STD OF MEAN	1.133-003	1.714+001		
AVE PER CENT CHANGE	-6.762+001	5.454+000		
INTERVAL ESTIMATE	-8.239+001	4.579+000		
AS PER CENT	-5.328+001	5.937+000		
PER CENT AVE CHANGE	-6.783+001	5.258+000		
GROUP C				
NUMBER	3	3		
INITIAL MEAN	8.800-003	4.195+003		
AVERAGE CHANGE	-3.700-003	1.048+002		
STD OF MEAN	4.121-003	1.310+002		
AVE PER CENT CHANGE	-4.162+001	2.695+000		
INTERVAL ESTIMATE	-1.370+002	-3.838+000		
AS PER CENT	5.294+001	8.835+000		
PER CENT AVE CHANGE	-4.205+001	2.498+000		
F-TEST	1.464+000	8.995-001	0.000+000	0.000+000
T-TEST				
GROUPS P-D	1.368+000	-1.226+000	0.000+000	0.000+000
GROUPS P-S	4.597+000	-3.836+000	0.000+000	0.000+000
GROUPS P-C	2.025+000	-1.904+000		
GROUPS D-S	1.975+000	-1.584+000		
GROUPS D-C	4.643-001	-4.792-001		
GROUPS S-C	-1.479+000	1.072+000		

CODE MC962

	T-RISE	T-FALL	T-DELAY	T-STORE
UNITS	NS	NS	NS	NS
GROUP P				
NUMBER	0	0	0	0
INITIAL MEAN	0.000+000	0.000+000	0.000+000	0.000+000
AVERAGE CHANGE	0.000+000	0.000+000	0.000+000	0.000+000
STD OF MEAN	-0.000+000	-0.000+000	-0.000+000	-0.000+000
AVE PER CENT CHANGE	0.000+000	0.000+000	0.000+000	0.000+000
INTERVAL ESTIMATE	0.000+000	0.000+000	0.000+000	0.000+000
AS PER CENT	0.000+000	0.000+000	0.000+000	0.000+000
PER CENT AVE CHANGE	0.000+000	0.000+000	0.000+000	0.000+000
GROUP D				
NUMBER	3	3	3	3
INITIAL MEAN	7.500+000	2.120+002	1.020+001	2.583+001
AVERAGE CHANGE	2.333+000	2.967+001	1.467+000	-5.000-001
STD OF MEAN	3.677+000	1.420+001	6.745-001	5.842+000
AVE PER CENT CHANGE	3.209+001	1.418+001	1.450+001	-1.860+000
INTERVAL ESTIMATE	-6.834+001	4.116-001	9.647-001	-4.780+001
AS PER CENT	1.306+002	2.758+001	2.779+001	4.393+001
PER CENT AVE CHANGE	3.111+001	1.399+001	1.438+001	-1.935+000
GROUP S				
NUMBER	4	4	4	4
INITIAL MEAN	6.675+000	1.913+002	9.525+000	2.480+001
AVERAGE CHANGE	4.700+000	3.000+001	1.725+000	-5.300+000
STD OF MEAN	1.871+000	4.110+000	1.106-001	1.170+000
AVE PER CENT CHANGE	6.895+001	1.570+001	1.815+001	-2.129+001
INTERVAL ESTIMATE	3.178+001	1.273+001	1.651+001	-2.787+001
AS PER CENT	1.090+002	1.865+001	1.971+001	-1.487+001
PER CENT AVE CHANGE	7.041+001	1.569+001	1.811+001	-2.137+001
GROUP C				
NUMBER	3	3	3	3
INITIAL MEAN	6.000+000	1.900+002	8.933+000	2.363+001
AVERAGE CHANGE	2.500+000	3.167+001	1.233+000	-2.633+000
STD OF MEAN	2.384+000	1.476+001	6.042-001	5.559+000
AVE PER CENT CHANGE	4.225+001	1.684+001	1.371+001	-1.056+001
INTERVAL ESTIMATE	-3.894+001	9.036-001	8.774-002	-5.886+001
AS PER CENT	1.223+002	3.243+001	2.752+001	3.657+001
PER CENT AVE CHANGE	4.167+001	1.667+001	1.381+001	-1.114+001
F-TEST	7.498-001	2.366-002	7.480-001	8.972-001
T-TEST				
GROUPS P-D	-1.711+000	-5.150+000	-5.878+000	2.239-001
GROUPS P-S	-3.979+000	-6.013+000	-7.982+000	2.740+000
GROUPS P-C	-1.833+000	-5.497+000	-4.942+000	1.179+000
GROUPS D-S	-1.312+000	-4.374-002	-7.826-001	1.625+000
GROUPS D-C	-8.640-002	-2.455-001	6.612-001	6.754-001
GROUPS S-C	1.219+000	-2.187-001	1.489+000	-9.026-001

CONCLUSIONS

The research described in this report has extended the knowledge of the effects of space radiation on silicon integrated circuits including MOS digital circuitry. The results should provide the space-systems design engineer with expanded capabilities in selection of integrated circuits for use in future space systems.

Several significant findings are warranted by the research results. These are

(1) To reaffirm and extend a conclusion from last year's report. The radiation resistance of present silicon integrated circuits is determined by the stability of gain of the transistor elements with respect to electron exposure and the tolerance of circuit design with respect to changes in gain.

(2) For surface-sensitive devices and circuits operated at low current and/or high impedance, surface damage can cause sufficient leakage currents and/or gain degradation to result in device failure.

(3) For MOS digital circuits and circuits with complimentary transistor outputs, the V_{one} output level can decrease sufficiently to cause failure of the device. As a result of the way these devices are loaded, decreases in fan-out may or may not effect the period of satisfactory operation in a radiation environment.

(4) No excessive temporary changes occurred in the unbiased samples during irradiation.

(5) Amplifiers and MOS digital circuitry will be more sensitive to the space radiation environment than will most digital circuits.

(6) The circuits which appeared to be failing from surface damage showed less degradation for the unbiased units than for the biased units. However, the circuits which appeared to have some damage due to bulk effects seem to show more degradation for the nonenergized circuits than for the energized circuits.

The research also has raised several questions which remain unanswered at this point. The problem of failures due apparently to surface damage is a good example. If the early failures were caused by rate effects or surface damage, it would be interesting to know which electron energies are most deleterious.